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(54) **REPLICATION AND RESTORATION**

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CPC ***G06F 17/30194*** (2013.01); ***G06F 17/30215*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 17/30194; G06F 17/30575; G06F 17/30215; G06F 17/30073
USPC 707/639
See application file for complete search history.

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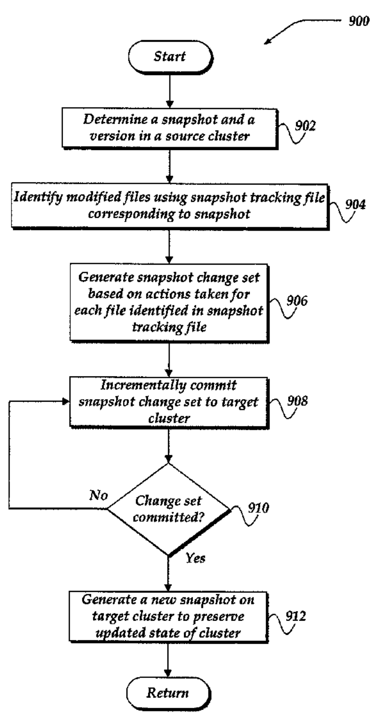
(57) **ABSTRACT**

Embodiments are directed towards replication and restoration of file system objects stored on file system clusters. Modified file system objects may be tracked using a snapshot tracking file corresponding to a snapshot. The snapshot tracking file may be employed to generate a snapshot change set. The snapshot change set may be used to restore a file system cluster to a version corresponding to a snapshot by reversing the changes in the snapshot change set. Also, a snapshot change set may be used to replicate file system objects by committing the included changes on another file system cluster. If a primary file system cluster becomes unavailable the file system may failover to the secondary file system cluster. If the primary file system cluster later becomes available it may be restored by using snapshot change sets generated on the secondary file system cluster.

18 Claims, 16 Drawing Sheets



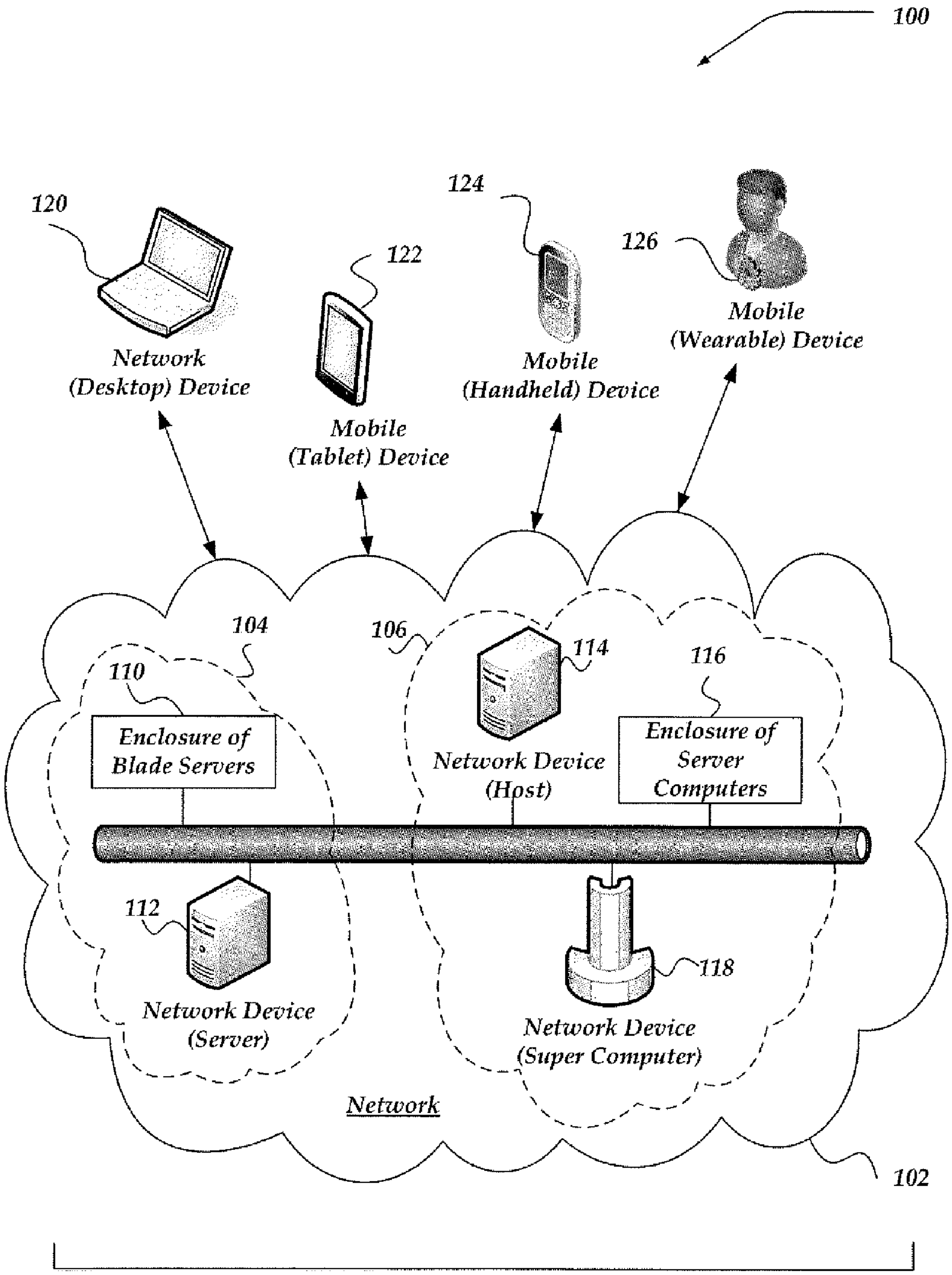

100
120
Network
(Desktop) Device
122
Mobile
(Tablet) Device
124
Mobile
(Handheld) Device
126
Mobile
(Wearable) Device
104
106
110
Enclosure of
Blade Servers
114
Network Device
(Host)
116
Enclosure of
Server
Computers
112
Network Device
(Server)
118
Network Device
(Super Computer)
Network
102

Fig. 1

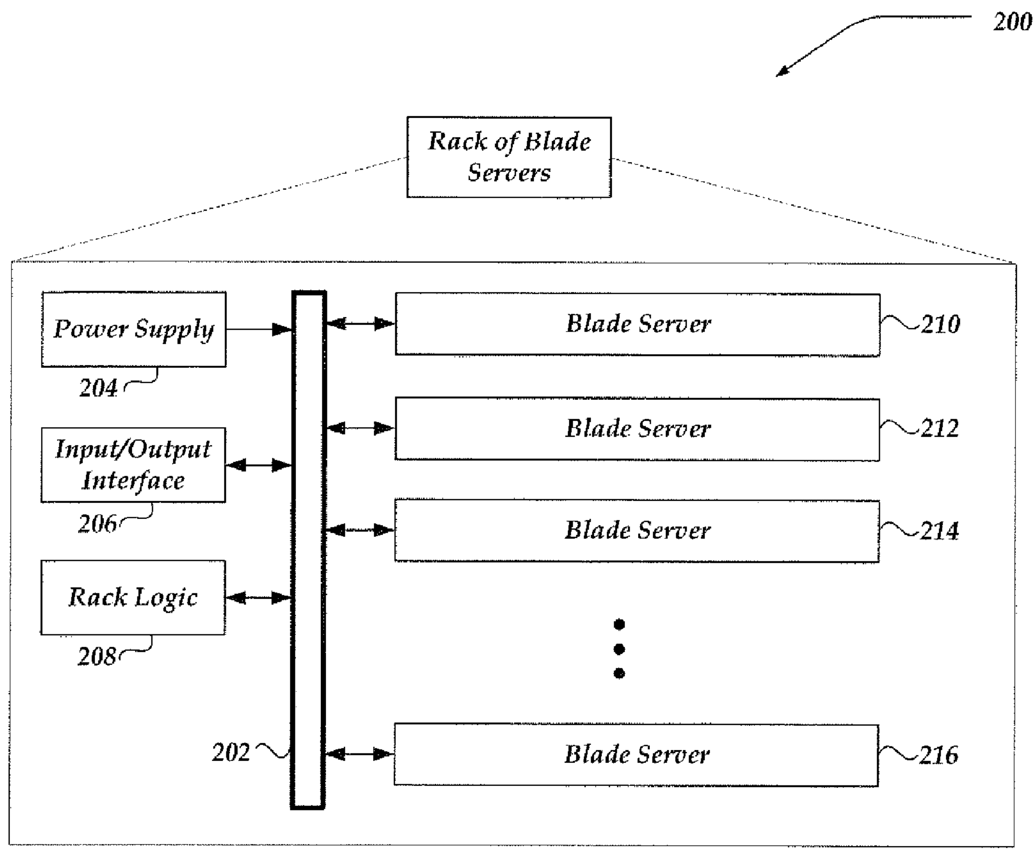

200
Rack of Blade Servers
Power Supply
204
Input/Output Interface
206
Rack Logic
208
202
Blade Server
210
Blade Server
212
Blade Server
214
Blade Server
216

Fig. 2A

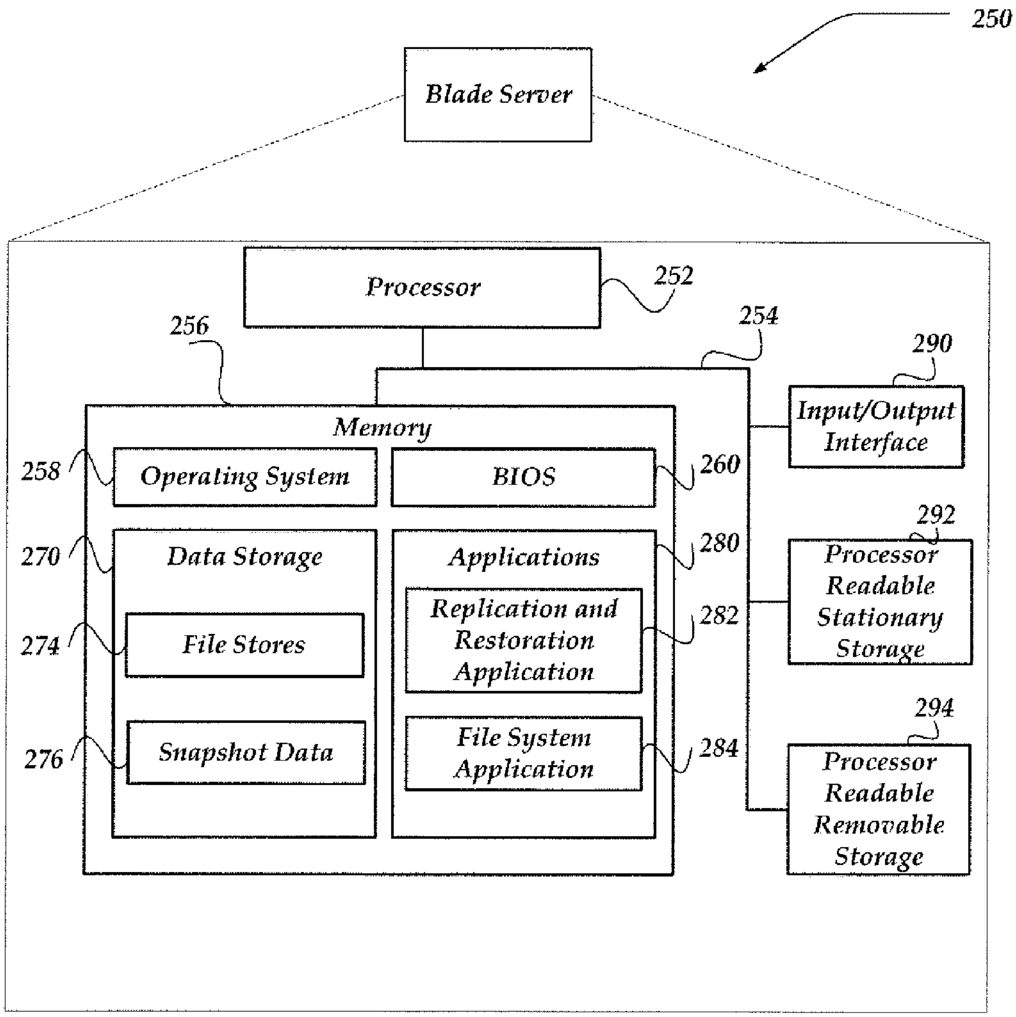

250
Blade Server
Processor
252
254
256
290
Input/Output Interface
Memory
258
Operating System
BIOS
260
292
270
Data Storage
Applications
280
Processor Readable Stationary Storage
Replication and Restoration Application
282
274
File Stores
294
276
Snapshot Data
File System Application
284
Processor Readable Removable Storage

Fig. 2B

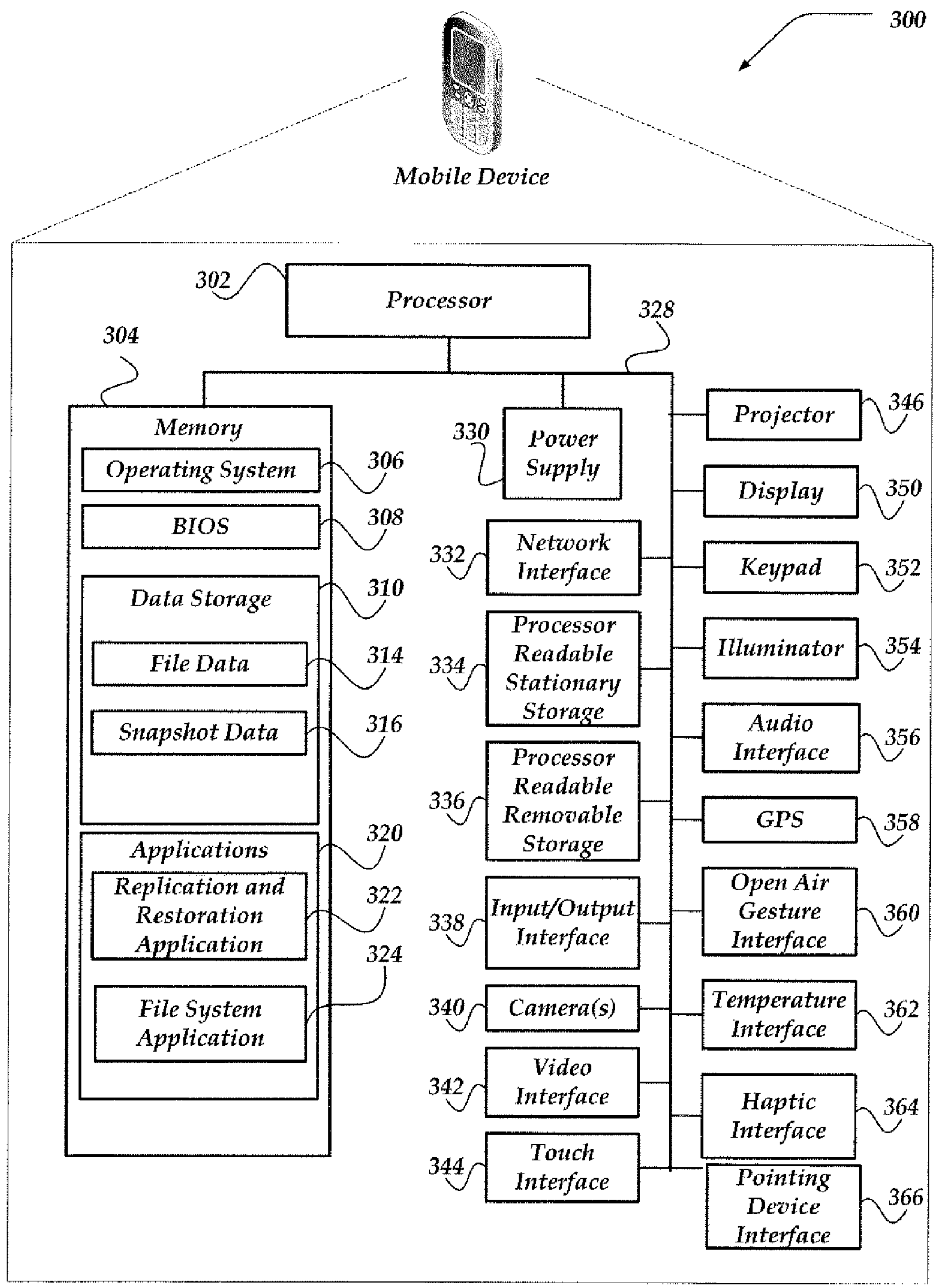

300
Mobile Device
302
Processor
328
304
Memory
Operating System
306
BIOS
308
Data Storage
310
File Data
314
Snapshot Data
316
Applications
320
Replication and Restoration Application
322
324
File System Application
330
Power Supply
332
Network Interface
334
Processor Readable Stationary Storage
336
Processor Readable Removable Storage
338
Input/Output Interface
340
Camera(s)
342
Video Interface
344
Touch Interface
Projector
346
Display
350
Keypad
352
Illuminator
354
Audio Interface
356
GPS
358
Open Air Gesture Interface
360
Temperature Interface
362
Haptic Interface
364
Pointing Device Interface
366

Fig. 3

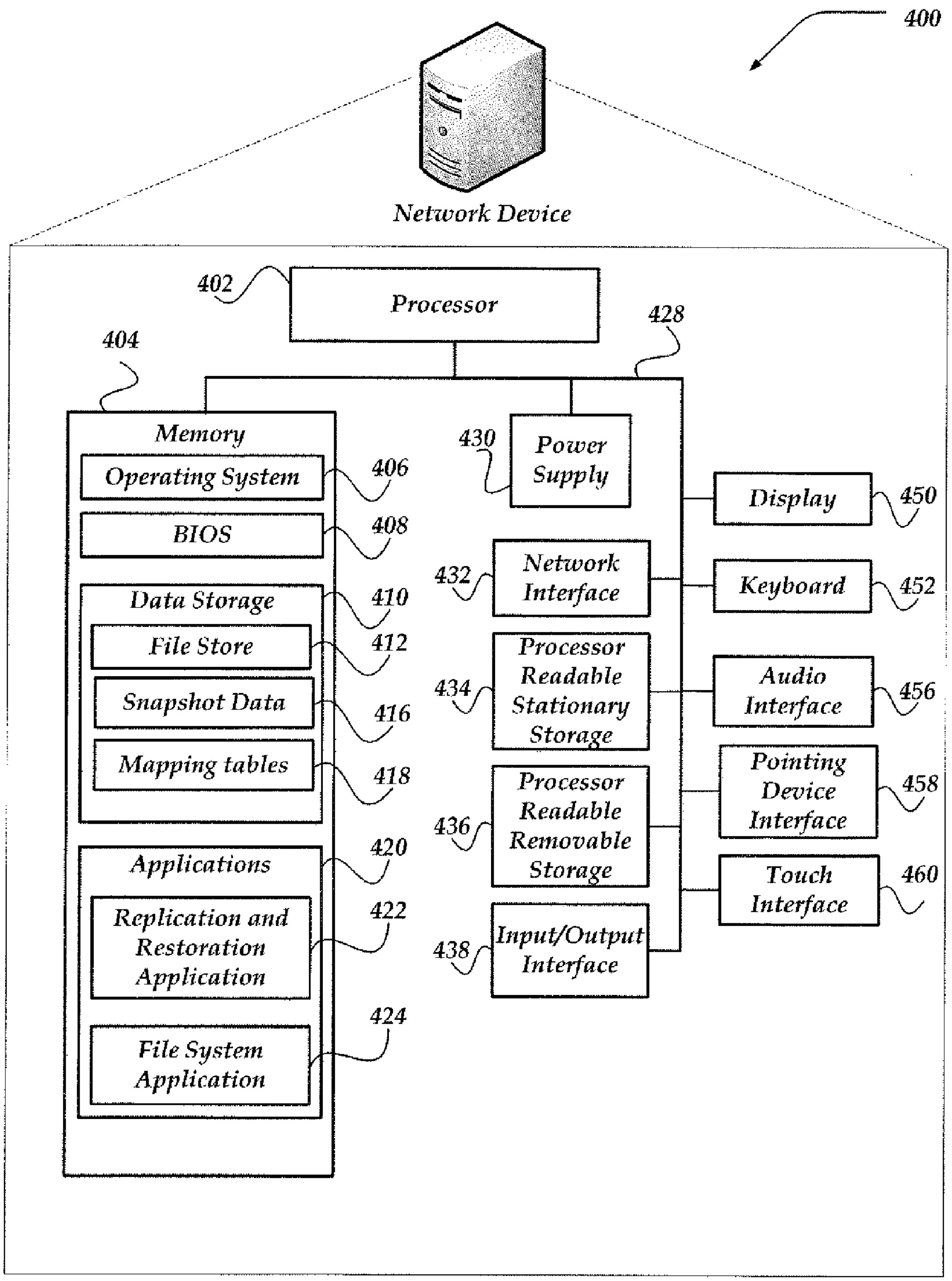

400
Network Device
Processor
402
404
428
Memory
Operating System
406
BIOS
408
Data Storage
410
File Store
412
Snapshot Data
416
Mapping tables
418
Applications
420
Replication and Restoration Application
422
File System Application
424
430
Power Supply
432
Network Interface
434
Processor Readable Stationary Storage
436
Processor Readable Removable Storage
438
Input/Output Interface
Display
450
Keyboard
452
Audio Interface
456
Pointing Device Interface
458
Touch Interface
460

Fig. 4

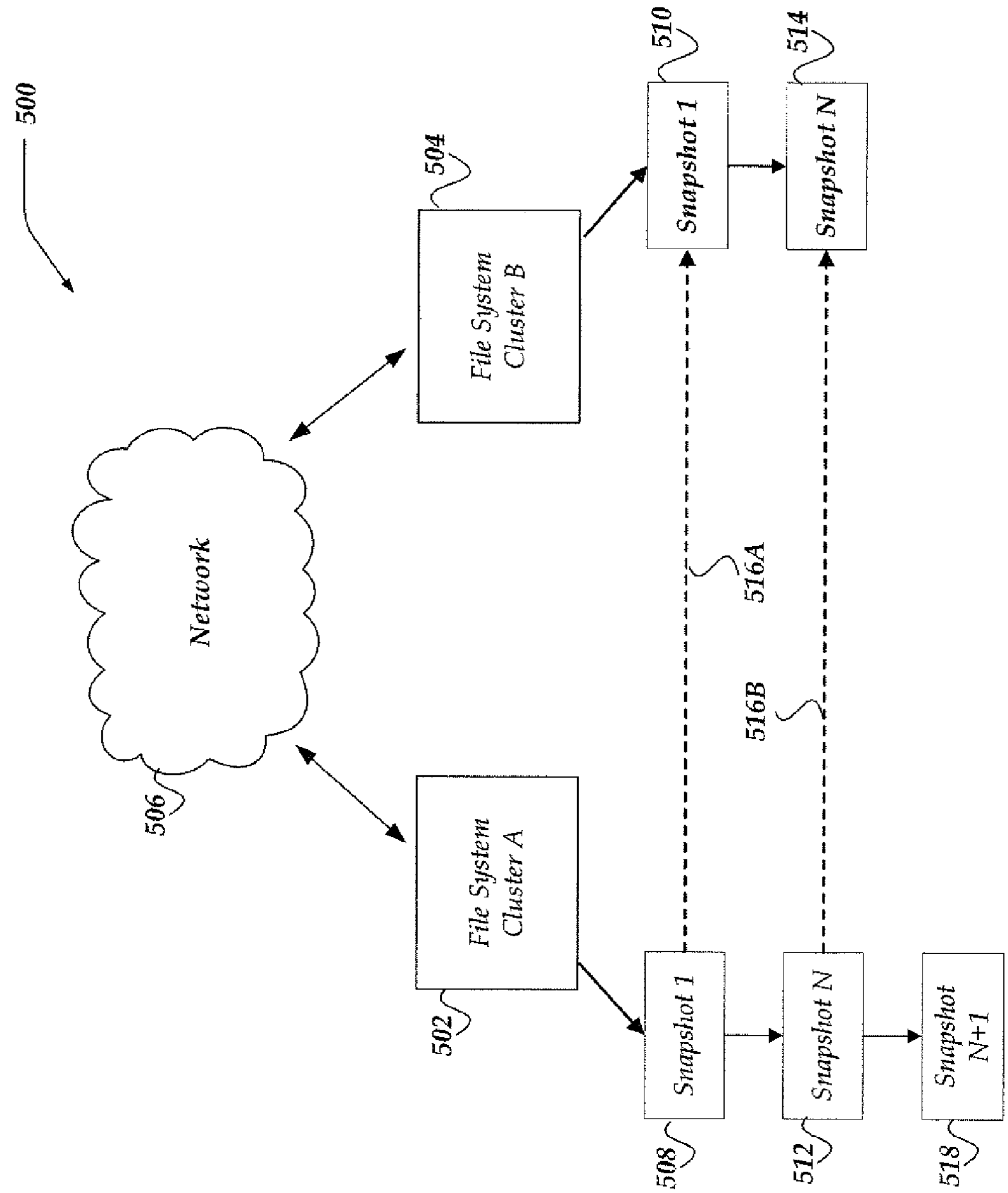

500
Network
506
File System Cluster A
502
File System Cluster B
504
Snapshot 1
508
Snapshot N
512
Snapshot N+1
518
Snapshot 1
510
Snapshot N
514
516A
516B

Fig. 5

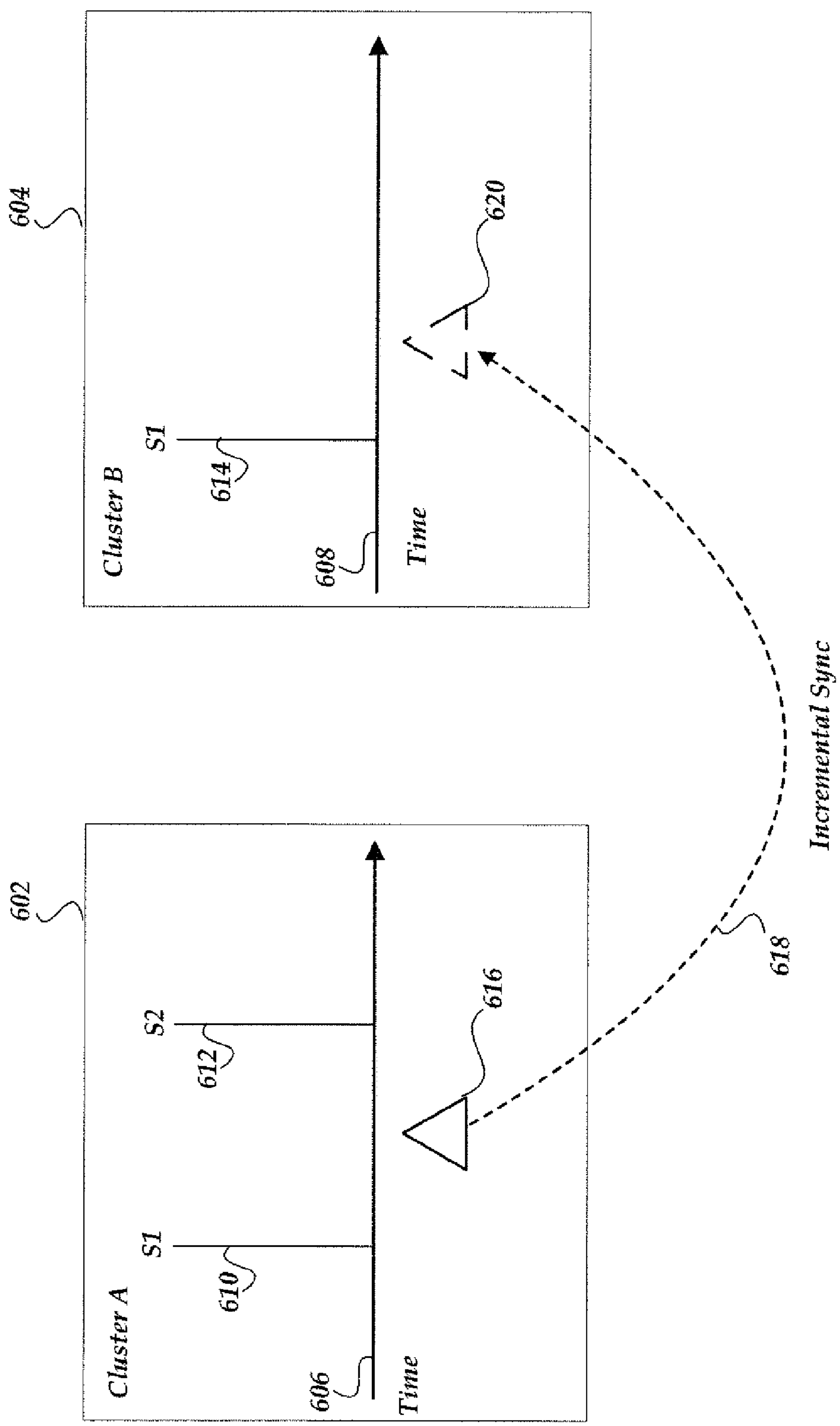

602
Cluster A
606
Time
S1
610
S2
612
616
604
Cluster B
608
Time
S1
614
620
618
Incremental Sync

Fig. 6A

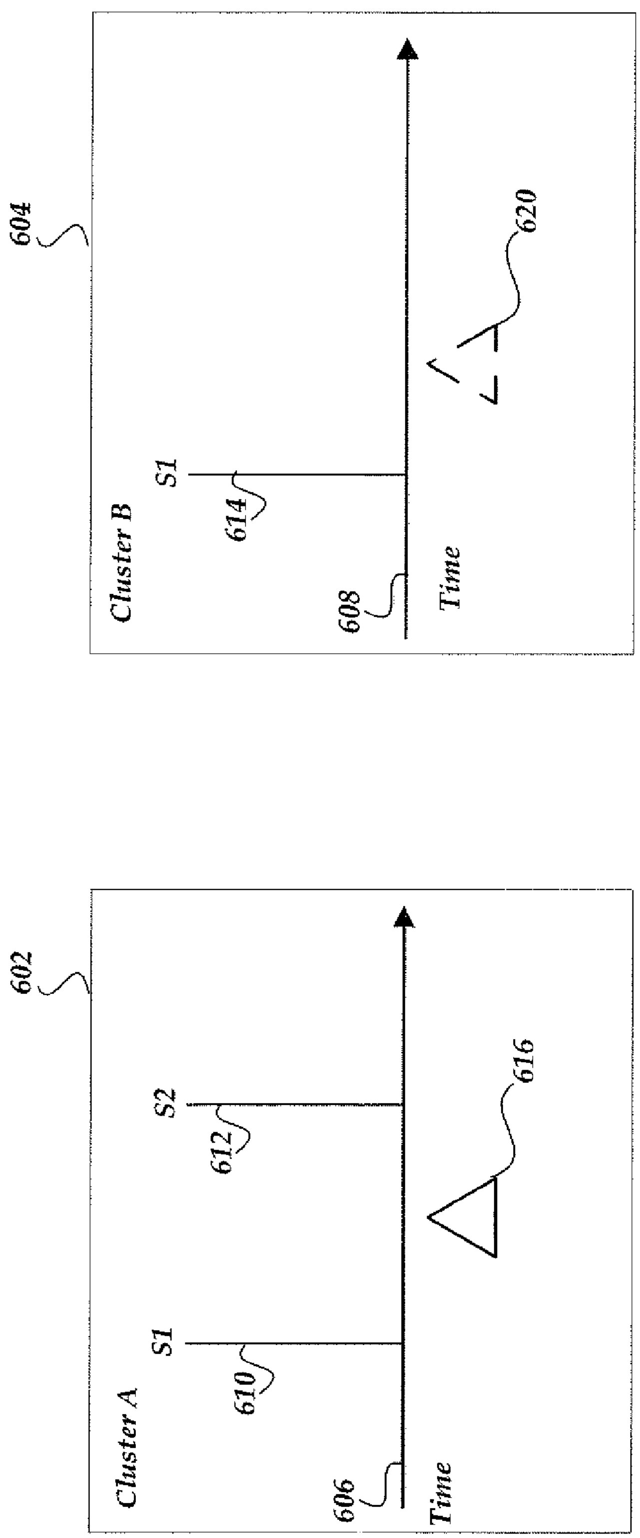

604
Cluster B
S1
614
608
Time
620
602
Cluster A
S1
S2
610
612
606
Time
616

Fig. 6B

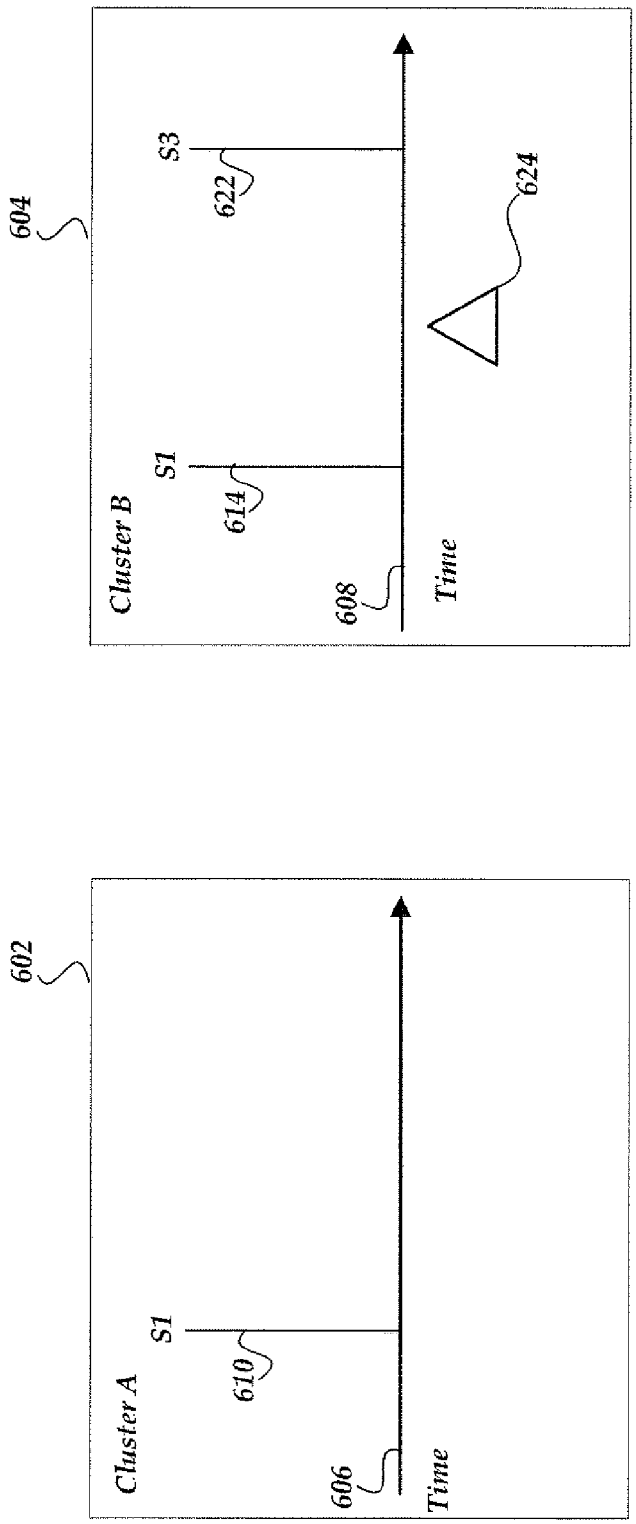
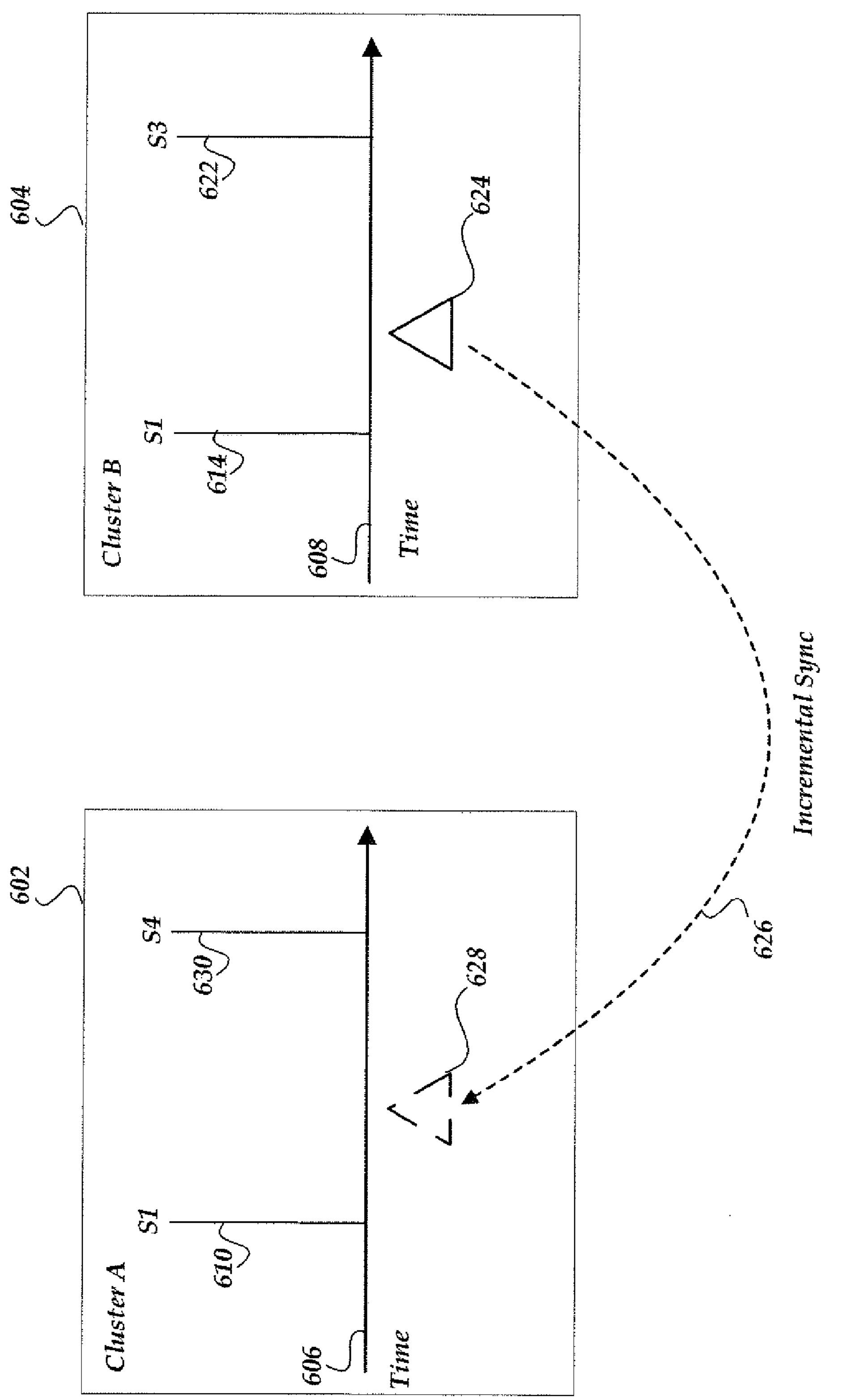

604
Cluster B
S1
S3
614
622
608
Time
624
602
Cluster A
S1
610
606
Time

Fig. 6C



604
Cluster B
S1
S3
614
622
608
624
Time
602
Cluster A
S1
S4
610
630
606
628
Time
Incremental Sync
626

Fig. 6D

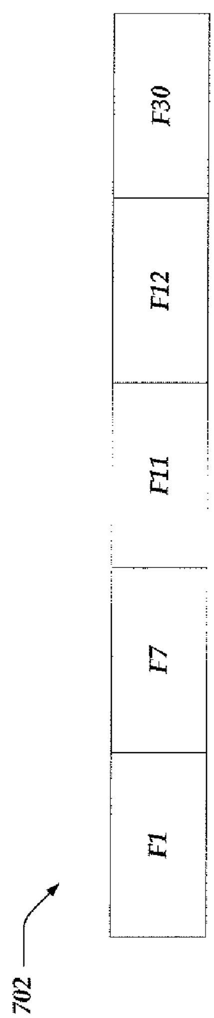

702
F1
F7
F11
F12
F30

Fig. 7A

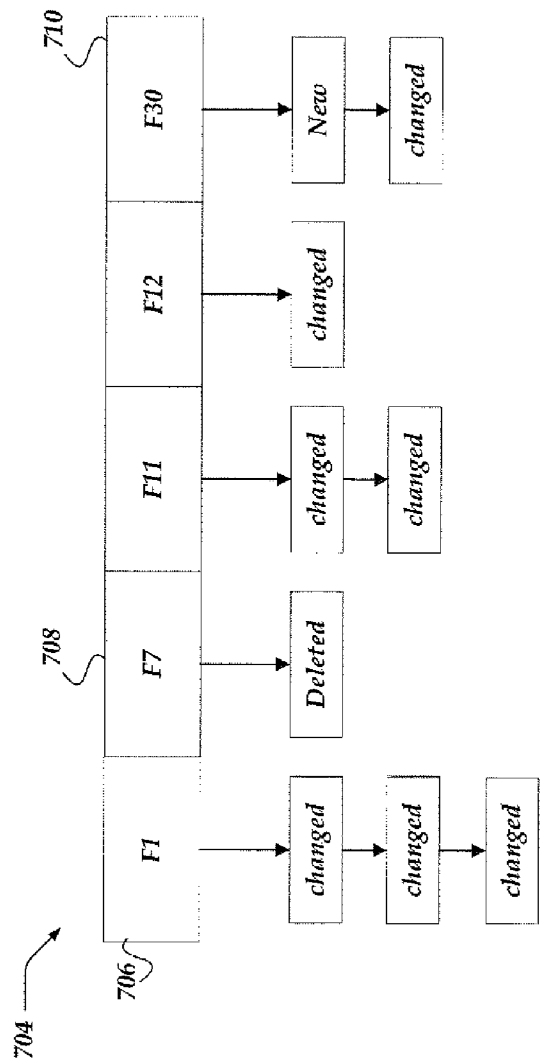

704
706
708
710
F1
F7
F11
F12
F30
changed
changed
changed
Deleted
changed
changed
changed
New
changed

Fig. 7B

802

Cluster A LIN Map

Local	Remote
F10	F30
F11	F31
F3	F11
F20	F34
F4	F12
F5	F13
F6	F14
F40	F2

806

804

Cluster B LIN Map

Local	Remote
F30	F10
F31	F11
F11	F3
F34	F20
F12	F4
F13	F5
F14	F6
F2	F40

808

Fig. 8

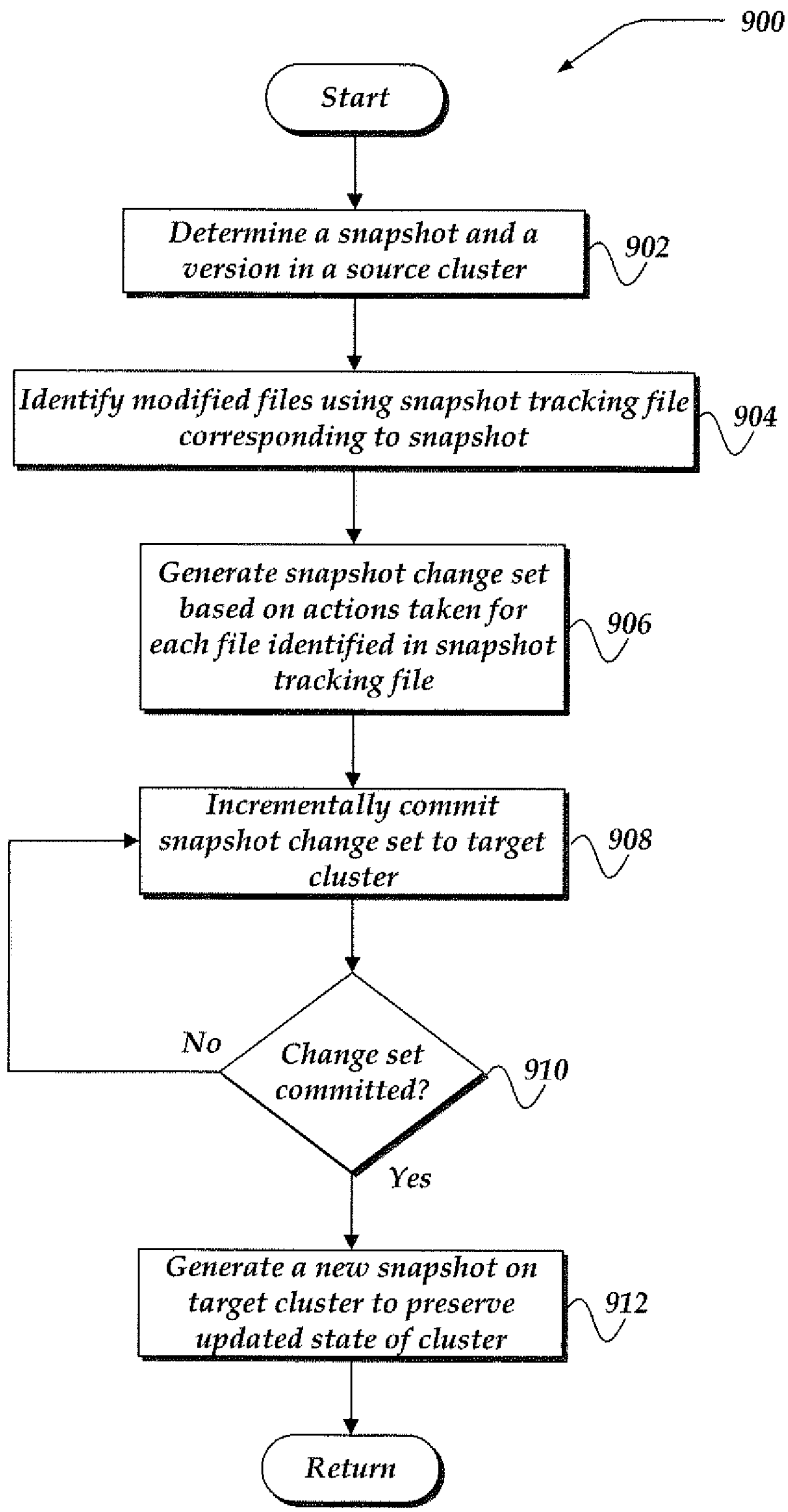

900
Start
Determine a snapshot and a version in a source cluster
902
Identify modified files using snapshot tracking file corresponding to snapshot
904
Generate snapshot change set based on actions taken for each file identified in snapshot tracking file
906
Incrementally commit snapshot change set to target cluster
908
No
Change set committed?
910
Yes
Generate a new snapshot on target cluster to preserve updated state of cluster
912
Return

Fig. 9

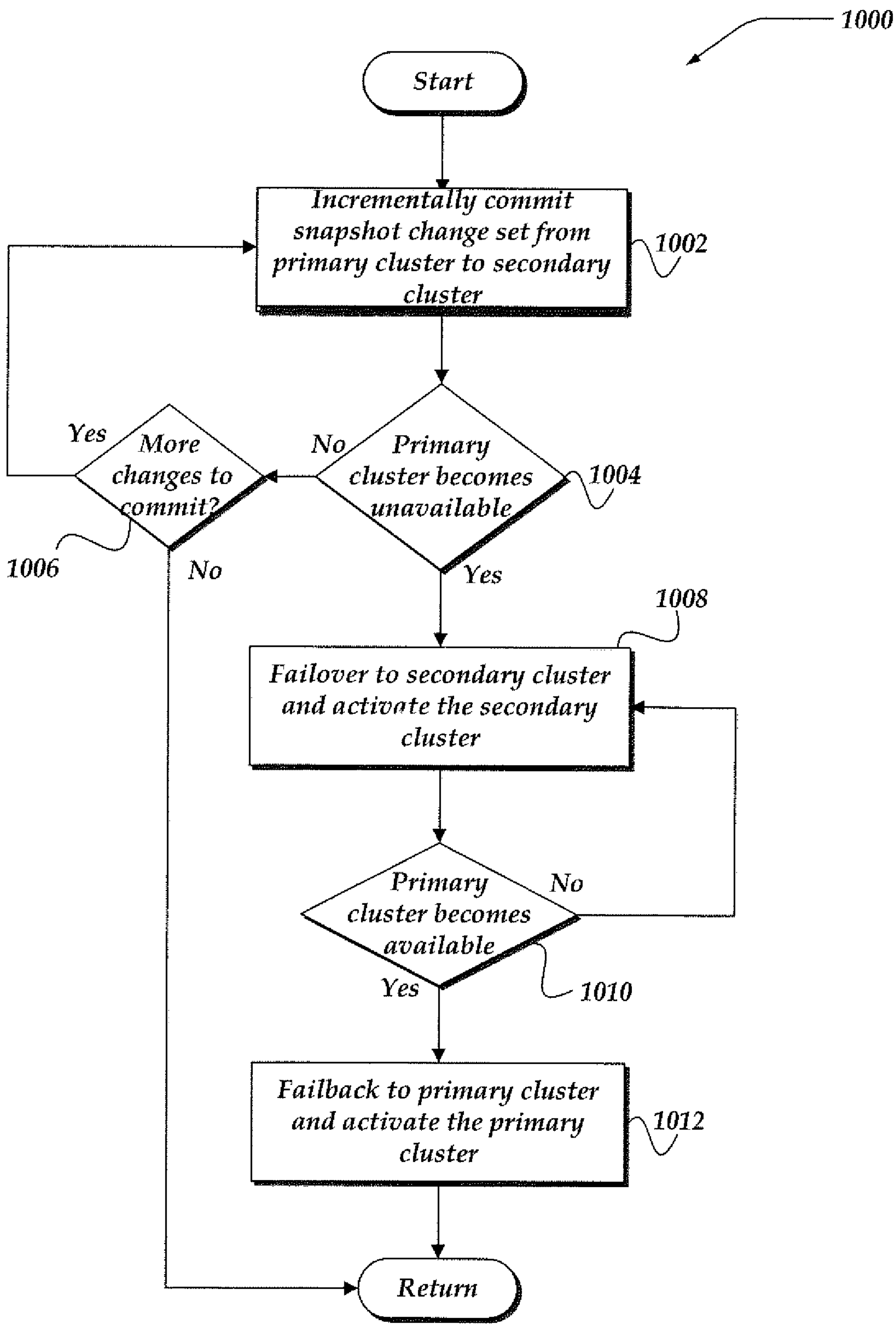

1000
Start
Incrementally commit snapshot change set from primary cluster to secondary cluster
1002
Primary cluster becomes unavailable
1004
No
Yes
More changes to commit?
1006
Yes
No
1008
Failover to secondary cluster and activate the secondary cluster
Primary cluster becomes available
No
Yes
1010
Failback to primary cluster and activate the primary cluster
1012
Return

Fig. 10

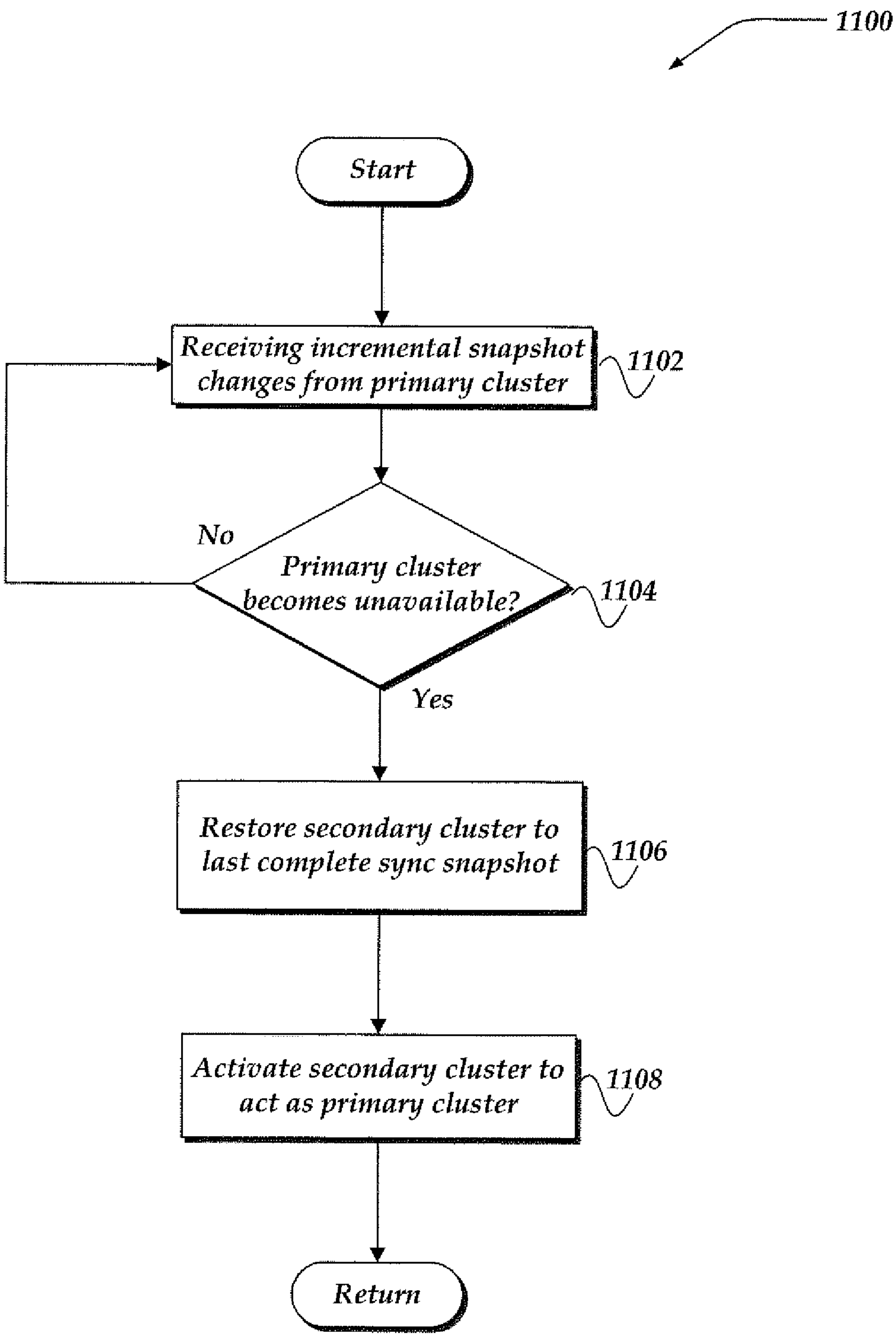

1100
Start
Receiving incremental snapshot changes from primary cluster
1102
No
Primary cluster becomes unavailable?
1104
Yes
Restore secondary cluster to last complete sync snapshot
1106
Activate secondary cluster to act as primary cluster
1108
Return

Fig. 11

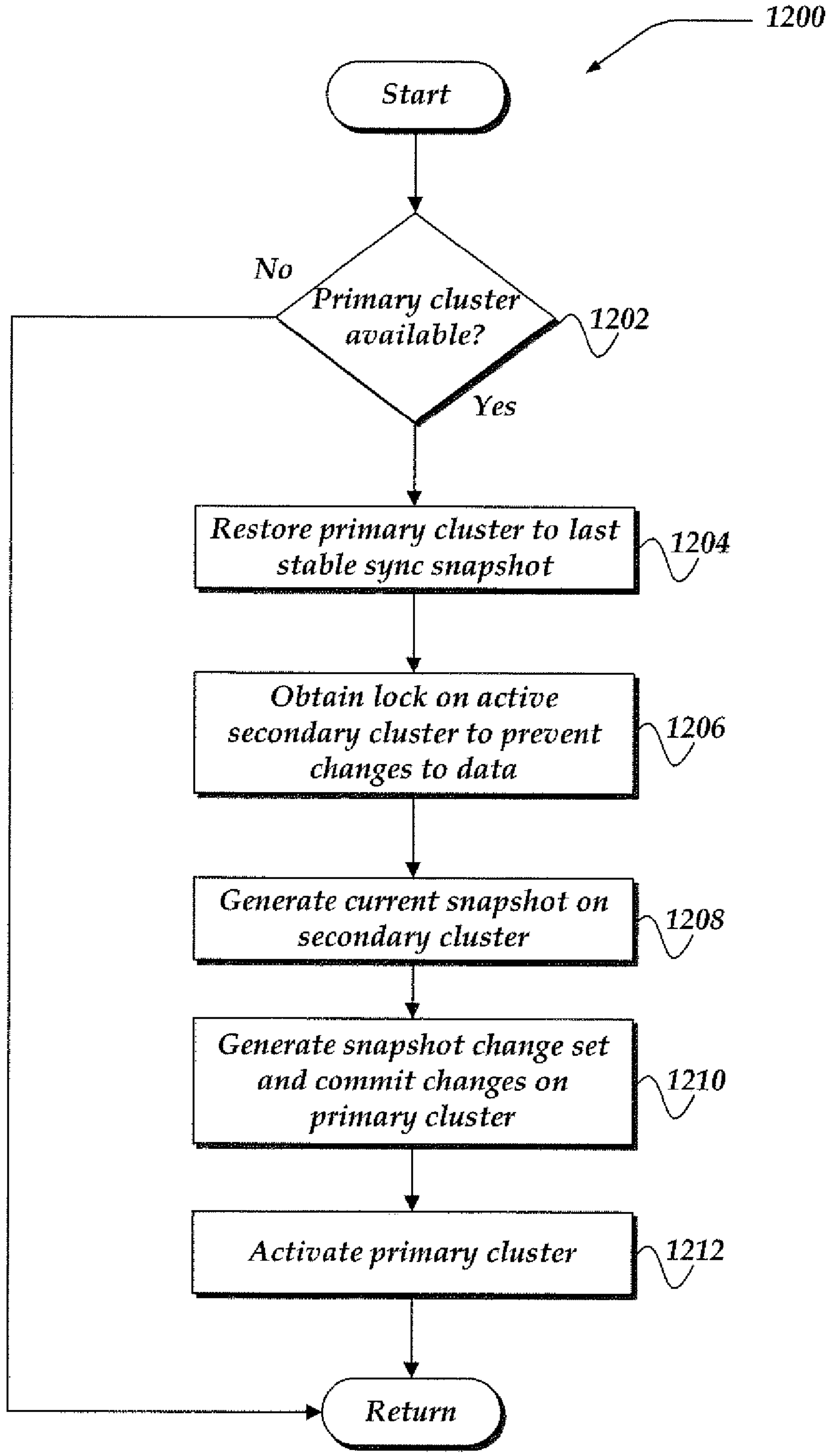

1200
Start
No
Primary cluster available?
1202
Yes
Restore primary cluster to last stable sync snapshot
1204
Obtain lock on active secondary cluster to prevent changes to data
1206
Generate current snapshot on secondary cluster
1208
Generate snapshot change set and commit changes on primary cluster
1210
Activate primary cluster
1212
Return

Fig. 12

REPLICATION AND RESTORATION

TECHNICAL FIELD

The various embodiments relate generally to managing storage of files in a distributed file system and more particularly to, improving performance by enabling replication and restoration of file systems in a distributed computing environment.

BACKGROUND

High performance computing environments often require distributed high performance file systems. Such file systems may be responsible for storing and managing access to millions of files. In some cases, such file systems may have to provide files for thousands, or even millions of simultaneous users.

Supporting robust replication and restoration operations are important requirements for high performance file systems. Typically, distributed file systems may employ backup systems that mirror the data stored on the primary file system. However, for long running backup processes in operating in high performance computing environments backup and mirroring processed may be interrupted in the middle of the backup and/or restoration process. Such interruption may create inconsistent backups that may be difficult to or impossible to generate accurate point-in-time restorations. Thus, it is with respect to these considerations and others that the present invention has been made.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting and non-exhaustive embodiments are described with reference to the following drawings. In the drawings, like reference numerals refer to like parts throughout the various figures unless otherwise specified.

For a better understanding, reference will be made to the following Description Of The Various Embodiments, which is to be read in association with the accompanying drawings, wherein:

FIG. **1** illustrates a system environment in which various embodiments may be implemented;

FIG. **2**A shows a schematic drawing of a rack of blade servers;

FIG. **2**B illustrates a schematic embodiment of a blade server that may be included in a rack of blade servers such as that shown in FIG. **2**A;

FIG. **3** shows a schematic embodiment of a mobile device;

FIG. **4** illustrates a schematic embodiment of a network device;

FIG. **5** illustrates an overview of file cluster mirroring in accordance with at least one of the various embodiments;

FIGS. **6**A-**6**D illustrate an overview of the failover-failback procedure in accordance with at least one of the various embodiments;

FIGS. **7**A-**7**B illustrate an logical representation of a snapshot tracking file and a snapshot change set in accordance with at least one of the various embodiments;

FIG. **8** shows logical representations of cluster logical inode maps in accordance with at least one of the various embodiments;

FIG. **9** shows a flow chart for a process of restoring/replication changes between snapshots in accordance with at least one of the various embodiments;

FIG. **10** shows a flow chart for a process of failover and failback between a primary file system cluster and a secondary file system cluster;

FIG. **11** shows a flow chart for a failover process in accordance with at least one of the various embodiments;

FIG. **12** shows a flow chart for a failback process in accordance with at least one of the various embodiments.

DESCRIPTION OF THE VARIOUS EMBODIMENTS

The invention now will be described more fully hereinafter with reference to the accompanying drawings, which form a part hereof, and which show, by way of illustration, specific embodiments by which the invention may be practiced. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Among other things, the invention may be embodied as methods or devices. Accordingly, the invention may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects. The following detailed description is, therefore, not to be taken in a limiting sense.

Throughout the specification and claims, the following terms take the meanings explicitly associated herein, unless the context clearly dictates otherwise. The phrase “in one embodiment” as used herein does not necessarily refer to the same embodiment, though it may. Furthermore, the phrase “in another embodiment” as used herein does not necessarily refer to a different embodiment, although it may. Thus, as described below, various embodiments may be readily combined, without departing from the scope or spirit of the invention.

In addition, as used herein, the term “or” is an inclusive “or” operator, and is equivalent to the term “and/or,” unless the context clearly dictates otherwise. The term “based on” is not exclusive and allows for being based on additional factors not described, unless the context clearly dictates otherwise. In addition, throughout the specification, the meaning of “a,” “an,” and “the” include plural references. The meaning of “in” includes “in” and “on.”

Various embodiments now will be described more fully hereinafter with reference to the accompanying drawings, which form a part hereof, and which show, by way of illustration, specific exemplary embodiments by which the invention may be practiced. The embodiments may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the embodiments to those skilled in the art. Among other things, the various embodiments may be methods, systems, media or devices. Accordingly, the various embodiments may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects. The following detailed description is, therefore, not to be taken in a limiting sense.

For example embodiments, the following terms are also used herein according to the corresponding meaning, unless the context clearly dictates otherwise.

The term “inode,” as used herein refers to data structures that may store information, or meta-data, about files and folders, such as size, file ownership, access mode (read, write, execute permissions), time and date of creation and modification, file type, or the like. In at least one of the various embodiments, inode data structures may contain one or more references or pointer to the actual data blocks of the contents stored in the file. In at least one of the various embodiments, inodes may be in a known location in a file system. From an inode, a reader or writer may access the contents of the inode and the contents of the file. Some file systems implement inodes using a data structure called an inode. In at least one of the various embodiments, a data structure explicitly named "inode" may be absent, but file systems may have data structures that store data similar to inodes and may provide capabilities similar to inodes as described herein. Also, in at least one of the various embodiments, the inode data may be referred to as stat data, in reference to the stat system call that provides the data to processes.

The terms "snapshot," or "snapshots" as used herein refer to a data structure that maintains a stable image in a well-defined state for one or more files system objects in a file system. Snapshots preserve point-in-time consistent state and/or contents of one or more file system objects. Snapshots may enable the state and/or contents of file system object to be preserved based on the point-in-time the snapshot was generated. In at least one of the various embodiments, snapshots may be generated on demand or automatically (e.g., event driven and/or timer driven).

In at least one of the various embodiments, if a data block in a file is about to be modified it may be copied from the file to the snapshot to preserve the block. Data blocks in a file that remain unmodified may be absent from the snapshot data structure. Thus, in at least one of the various embodiments, a snapshot may be a sparse copy of the file contents with unmodified data blocks remaining in the file rather than being copied to the snapshot.

The term "file system object," as used herein refers to the various objects that may be included and/or stored in a file system, such as files, inodes, directories, symbolic links, hard links, or the like.

The term "synchronized snapshot," as used herein refers to snapshot that is guaranteed to the synchronized between two or more file system clusters. In at least one of the various embodiments, the file system objects content/state is guaranteed to be consistent across file system clusters corresponding to the synchronized snapshot. Thus, if file system cluster are restored to the same synchronized snapshot, the file system objects will be logically the same on each file system cluster.

The term "LIN," as used herein refers to a logical inode that may be used to identify and reference file system objects in a file system.

The term "failover" as used herein refers to a process may be employed to bring a secondary file system cluster online and active if a primary file system cluster becomes unavailable.

The term "failback" as used herein refers to a process may be employed to bring a primary file system cluster back online after it becomes available after failover.

The term "version," or "file system cluster version" as used herein refers to the state/contents of a file system at a point-in-time. In at least one of the various embodiments, the head version may correspond to the latest version of the file system. Each snapshot of a file system may be considered to correspond to a version of the file system. However, versions may exist absent a corresponding snapshot (e.g., head version).

Briefly stated, various embodiments are directed towards replication and restoration of file system objects stored on file system clusters. In at least one of the various embodiments, snapshots may be employed to establish point-in-time versions of the file system cluster. Modified file system objects may be tracked using a snapshot tracking file corresponding to a snapshot. In at least one of the various embodiments, the snapshot tracking file may be employed to generate a snapshot change set that includes the changes made to file system objects subsequent to the generation of the snapshot.

In at least one of the various embodiments, a snapshot change set may be used to restore a file system cluster to the version corresponding to the snapshot by reversing the changes included in the snapshot change set. Also, in at least one of the various embodiments, the snapshot change set may be used to replicate file system objects from a primary file system cluster by committing the included changes on a secondary file system cluster.

In at least one of the various embodiments, a primary file system cluster may commit snapshot change sets onto a secondary file system cluster. If the primary file system cluster becomes unavailable the file system may failover to the secondary file system cluster. In at least one of the various embodiments, the secondary file system cluster may be restored to a consistent data point by restoring to a synchronized snapshot. In at least one of the various embodiments, if the primary file system cluster becomes available it may be restored by committing changes included in one or more snapshot change sets generated on the secondary file system cluster.

Illustrative Operating Environment

FIG. **1** shows components of an environment in which various embodiments may be practiced. Not all of the components may be required to practice the various embodiments, and variations in the arrangement and type of the components may be made without departing from the spirit or scope of the various embodiments.

In at least one embodiment, cloud network **102** enables one or more network services for a user based on the operation of corresponding arrangements **104** and **106** of virtually any type of networked computing device. As shown, the networked computing devices may include server network device **112**, host network device **114**, enclosure of blade servers **110**, enclosure of server computers **116**, super computer network device **118**, and the like. Although not shown, one or more mobile devices may be included in cloud network **102** in one or more arrangements to provide one or more network services to a user. Also, these arrangements of networked computing devices may or may not be mutually exclusive of each other.

Additionally, the user may employ a plurality of virtually any type of wired or wireless networked computing devices to communicate with cloud network **102** and access at least one of the network services enabled by one or more of arrangements **104** and **106**. These networked computing devices may include tablet mobile device **122**, handheld mobile device **124**, wearable mobile device **126**, desktop network device **120**, and the like. Although not shown, in various embodiments, the user may also employ notebook computers, desktop computers, microprocessor-based or programmable consumer electronics, network appliances, mobile telephones, smart telephones, pagers, radio frequency (RF) devices, infrared (IR) devices, Personal Digital Assistants (PDAs), televisions, integrated devices combining at least one of the preceding devices, and the like.

One embodiment of a mobile device is described in more detail below in conjunction with FIG. **3**. Generally, mobile devices may include virtually any substantially portable networked computing device capable of communicating over a wired, wireless, or some combination of wired and wireless network.

In various embodiments, network **102** may employ virtually any form of communication technology and topology. For example, network **102** can include local area networks Personal Area Networks (PANs), (LANs), Campus Area Networks (CANs), Metropolitan Area Networks (MANs) Wide Area Networks (WANs), direct communication connections, and the like, or any combination thereof. On an interconnected set of LANs, including those based on differing architectures and protocols, a router acts as a link between LANs, enabling messages to be sent from one to another. In addition, communication links within networks may include virtually any type of link, e.g., twisted wire pair lines, optical fibers, open air lasers or coaxial cable, plain old telephone service (POTS), wave guides, acoustic, full or fractional dedicated digital communication lines including T1, T2, T3, and T4, and/or other carrier and other wired media and wireless media. These carrier mechanisms may include E-carriers, Integrated Services Digital Networks (ISDNs), universal serial bus (USB) ports, Firewire ports, Thunderbolt ports, Digital Subscriber Lines (DSLs), wireless links including satellite links, or other communications links known to those skilled in the art. Moreover, these communication links may further employ any of a variety of digital signaling technologies, including without limit, for example, DS-0, DS-1, DS-2, DS-3, DS-4, OC-3, OC-12, OC-48, or the like. Furthermore, remotely located computing devices could be remotely connected to networks via a modem and a temporary communication link. In essence, network **102** may include virtually any communication technology by which information may travel between computing devices. Additionally, in the various embodiments, the communicated information may include virtually any kind of information including, but not limited to processor-readable instructions, data structures, program modules, applications, raw data, control data, archived data, video data, voice data, image data, text data, and the like.

Network **102** may be partially or entirely embodied by one or more wireless networks. A wireless network may include any of a variety of wireless sub-networks that may further overlay stand-alone ad-hoc networks, and the like. Such sub-networks may include mesh networks, Wireless LAN (WLAN) networks, Wireless Router (WR) mesh, cellular networks, pico networks, PANs, Open Air Laser networks, Microwave networks, and the like. Network **102** may further include an autonomous system of intermediate network devices such as terminals, gateways, routers, switches, firewalls, load balancers, and the like, which are coupled to wired and/or wireless communication links. These autonomous devices may be operable to move freely and randomly and organize themselves arbitrarily, such that the topology of network **102** may change rapidly.

Network **102** may further employ a plurality of wired and wireless access technologies, e.g., 2nd (2G), 3rd (3G), 4th (4G), 5^{th} (5G) generation wireless access technologies, and the like, for mobile devices. These wired and wireless access technologies may also include Global System for Mobile communication (GSM), General Packet Radio Services (GPRS), Enhanced Data GSM Environment (EDGE), Code Division Multiple Access (CDMA), Wideband Code Division Multiple Access (WCDMA), Long Term Evolution Advanced (LTE), Universal Mobile Telecommunications System (UMTS), Orthogonal frequency-division multiplexing (OFDM), Wideband Code Division Multiple Access (W-CDMA), Code Division Multiple Access 2000 (CDMA2000), Evolution-Data Optimized (EV-DO), High-Speed Downlink Packet Access (HSDPA), IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMax), ultra wide band (UWB), user datagram protocol (UDP), transmission control protocol/Internet protocol (TCP/IP), any portion of the Open Systems Interconnection (OSI) model protocols, Short Message Service (SMS), Multimedia Messaging Service (MMS), Web Access Protocol (WAP), Session Initiation Protocol/Real-time Transport Protocol (SIP/RTP), or any of a variety of other wireless or wired communication protocols. In one non-limiting example, network **102** may enable a mobile device to wirelessly access a network service through a combination of several radio network access technologies such as GSM, EDGE, SMS, HSDPA, LTE and the like.

Enclosure of Blade Servers

FIG. **2**A shows one embodiment of an enclosure of blade servers **200**, which are also illustrated in FIG. **1**. Enclosure of blade servers **200** may include many more or fewer components than those shown in FIG. **2**A. However, the components shown are sufficient to disclose an illustrative embodiment. Generally, a blade server is a stripped down server computing device with a modular design optimized to minimize the use of physical space and energy. A blade enclosure can include several blade servers and provide each with power, cooling, network interfaces, input/output interfaces, and resource management. Although not shown, an enclosure of server computers typically includes several computers that merely require a network connection and a power cord connection to operate. Each server computer often includes redundant components for power and interfaces.

As shown in the figure, enclosure **200** contains power supply **204**, and input/output interface **206**, rack logic **208**, several blade servers **210**, **212**, **214**, and **216**, and backplane **202**. Power supply **204** provides power to each component and blade server within the enclosure. The input/output interface **206** provides internal and external communication for components and blade servers within the enclosure. Backplane **208** can enable passive and active communication of power, logic, input signals, and output signals for each blade server.

Illustrative Blade Server

FIG. **2**B illustrates an illustrative embodiment of blade server **250**, which may include many more or fewer components than those shown. As shown in FIG. **2**A, a plurality of blade servers may be included in one enclosure that shares resources provided by the enclosure to reduce size, power, and cost.

Blade server **250** includes processor **252** which communicates with memory **256** via bus **254**. Blade server **250** also includes input/output interface **290**, processor-readable stationary storage device **292**, and processor-readable removable storage device **294**. Input/output interface **290** can enable blade server **250** to communicate with other blade servers, mobile devices, network devices, and the like. Interface **190** may provide wireless and/or wired communication links for blade server. Processor-readable stationary storage device **292** may include one or more devices such as an electromagnetic storage device (hard disk), solid state hard disk (SSD), hybrid of both an SSD and a hard disk, and the like. In some configurations, a blade server may include multiple storage devices. Also, processor-readable removable storage device **294** enables processor **252** to read non-transitive storage media for storing and accessing processor-readable instructions, modules, data structures, and other forms of data. The non-transitive storage media may include Flash drives, tape media, floppy media, and the like.

Memory **256** may include Random Access Memory (RAM), Read-Only Memory (ROM), hybrid of RAM and ROM, and the like. As shown, memory **256** includes operating system **258** and basic input/output system (BIOS) **260** for enabling the operation of blade server **250**. In various embodiments, a general-purpose operating system may be employed such as a version of UNIX, LINUX™, a specialized server operating system such as Microsoft's Windows Server™ and Apple Computer's IoS Server™, or the like.

Memory **256** further includes one or more data storage **270**, which can be utilized by blade server **250** to store, among other things, applications **280** and/or other data. Data stores **270** may include program code, data, algorithms, and the like, for use by processor **252** to execute and perform actions. In one embodiment, at least some of data store **270** might also be stored on another component of blade server **250**, including, but not limited to, processor-readable removable storage device **294**, processor-readable stationary storage device **292**, or any other processor-readable storage device (not shown). Data storage **270** may include, for example, file stores **274**, and snapshot data **276**.

Applications **280** may include processor executable instructions which, when executed by blade server **250**, transmit, receive, and/or otherwise process messages, audio, video, and enable communication with other networked computing devices. Examples of application programs include database servers, file servers, calendars, transcoders, and so forth. Applications **280** may include, for example, replication and restoration application **282**, and file system application **284**.

Human interface components (not pictured), may be remotely associated with blade server **250**, which can enable remote input to and/or output from blade server **250**. For example, information to a display or from a keyboard can be routed through the input/output interface **290** to appropriate peripheral human interface components that are remotely located. Examples of peripheral human interface components include, but are not limited to, an audio interface, a display, keypad, pointing device, touch interface, and the like.

Illustrative Mobile Device

FIG. **3** shows one embodiment of mobile device **300** that may include many more or less components than those shown. Mobile device **300** may represent, for example, at least one embodiment of mobile devices shown in FIG. **1**.

Mobile device **300** includes processor **302** in communication with memory **304** via bus **328**. Mobile device **300** also includes power supply **330**, network interface **332**, audio interface **356**, display **350**, keypad **352**, illuminator **354**, video interface **342**, input/output interface **338**, haptic interface **364**, global positioning systems (GPS) receiver **358**, Open air gesture interface **360**, temperature interface **362**, camera(s) **340**, projector **346**, pointing device interface **366**, processor-readable stationary storage device **334**, and processor-readable removable storage device **336**. Power supply **330** provides power to mobile device **300**. A rechargeable or non-rechargeable battery may be used to provide power. The power may also be provided by an external power source, such as an AC adapter or a powered docking cradle that supplements and/or recharges the battery. And in one embodiment, although not shown, a gyroscope may be employed within mobile device **300** to measuring and/or maintaining an orientation of mobile device **300**.

Mobile device **300** may optionally communicate with a base station (not shown), or directly with another computing device. Network interface **332** includes circuitry for coupling mobile device **300** to one or more networks, and is constructed for use with one or more communication protocols and technologies including, but not limited to, protocols and technologies that implement any portion of the Open Systems Interconnection (OSI) model for mobile communication (GSM), code division multiple access (CDMA), time division multiple access (TDMA), user datagram protocol (UDP), transmission control protocol/Internet protocol (TCP/IP), Short Message Service (SMS), Multimedia Messaging Service (MMS), general packet radio service (GPRS), Web Access Protocol (WAP), ultra wide band (UWB), IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMax), Session Initiation Protocol/Real-time Transport Protocol (SIP/RTP), General Packet Radio Services (GPRS), Enhanced Data GSM Environment (EDGE), Wideband Code Division Multiple Access (WCDMA), Long Term Evolution Advanced (LTE), Universal Mobile Telecommunications System (UMTS), Orthogonal frequency-division multiplexing (OFDM), Code Division Multiple Access 2000 (CDMA2000), Evolution-Data Optimized (EV-DO), High-Speed Downlink Packet Access (HSDPA), or any of a variety of other wireless communication protocols. Network interface **332** is sometimes known as a transceiver, transceiving device, or network interface card (NIC).

Audio interface **356** is arranged to produce and receive audio signals such as the sound of a human voice. For example, audio interface **356** may be coupled to a speaker and microphone (not shown) to enable telecommunication with others and/or generate an audio acknowledgement for some action. A microphone in audio interface **356** can also be used for input to or control of mobile device **300**, e.g., using voice recognition, detecting touch based on sound, and the like.

Display **350** may be a liquid crystal display (LCD), gas plasma, electronic ink, light emitting diode (LED), Organic LED (OLED) or any other type of light reflective or light transmissive display that can be used with a computing device. Display **350** may also include a touch interface **344** arranged to receive input from an object such as a stylus or a digit from a human hand, and may use resistive, capacitive, surface acoustic wave (SAW), infrared, radar, or other technologies to sense touch and/or gestures. Projector **346** may be a remote handheld projector or an integrated projector that is capable of projecting an image on a remote wall or any other reflective object such as a remote screen.

Video interface **342** may be arranged to capture video images, such as a still photo, a video segment, an infrared video, or the like. For example, video interface **342** may be coupled to a digital video camera, a web-camera, or the like. Video interface **342** may comprise a lens, an image sensor, and other electronics. Image sensors may include a complementary metal-oxide-semiconductor (CMOS) integrated circuit, charge-coupled device (CCD), or any other integrated circuit for sensing light.

Keypad **352** may comprise any input device arranged to receive input from a user. For example, keypad **352** may include a push button numeric dial, or a keyboard. Keypad **352** may also include command buttons that are associated with selecting and sending images. Illuminator **354** may provide a status indication and/or provide light. Illuminator **354** may remain active for specific periods of time or in response to events. For example, when illuminator **354** is active, it may backlight the buttons on keypad **352** and stay on while the mobile device is powered. Also, illuminator **354** may backlight these buttons in various patterns when particular actions are performed, such as dialing another mobile device. Illuminator **354** may also cause light sources positioned within a transparent or translucent case of the mobile device to illuminate in response to actions.

Mobile device **300** also comprises input/output interface **338** for communicating with external peripheral devices or other computing devices such as other mobile devices and network devices. The peripheral devices may include an audio headset, display screen glasses, remote speaker system, remote speaker and microphone system, and the like. Input/output interface **338** can utilize one or more technologies, such as Universal Serial Bus (USB), Infrared, WiFi, WiMax, Bluetooth™, and the like. Haptic interface **364** is arranged to provide tactile feedback to a user of the mobile device. For example, the haptic interface **364** may be employed to vibrate mobile device **300** in a particular way when another user of a computing device is calling. Temperature interface **362** may be used to provide a temperature measurement input and/or a temperature changing output to a user of mobile device **300**. Open air gesture interface **360** may sense physical gestures of a user of mobile device **300**, for example, by using single or stereo video cameras, radar, a gyroscopic sensor inside a device held or worn by the user, or the like. Camera **340** may be used to track physical eye movements of a user of mobile device **300**.

GPS transceiver **358** can determine the physical coordinates of mobile device **300** on the surface of the Earth, which typically outputs a location as latitude and longitude values. GPS transceiver **358** can also employ other geo-positioning mechanisms, including, but not limited to, triangulation, assisted GPS (AGPS), Enhanced Observed Time Difference (E-OTD), Cell Identifier (CI), Service Area Identifier (SAD, Enhanced Timing Advance (ETA), Base Station Subsystem (BSS), or the like, to further determine the physical location of mobile device **300** on the surface of the Earth. It is understood that under different conditions, GPS transceiver **358** can determine a physical location for mobile device **300**. In at least one embodiment, however, mobile device **300** may, through other components, provide other information that may be employed to determine a physical location of the device, including for example, a Media Access Control (MAC) address, IP address, and the like.

Human interface components can be peripheral devices that are physically separate from mobile device **300**, allowing for remote input and/or output to mobile device **300**. For example, information routed as described here through human interface components such as display **350** or keyboard **352** can instead be routed through network interface **332** to appropriate human interface components located remotely. Examples of human interface peripheral components that may be remote include, but are not limited to, audio devices, pointing devices, keypads, displays, cameras, projectors, and the like. These peripheral components may communicate over a Pico Network such as Bluetooth™, Zigbee™ and the like. One non-limiting example of a mobile device with such peripheral human interface components is a wearable computing device, which might include a remote pico projector along with one or more cameras that remotely communicate with a separately located mobile device to sense a user's gestures toward portions of an image projected by the pico projector onto a reflected surface such as a wall or the user's hand.

A mobile device may include a browser application that is configured to receive and to send web pages, web-based messages, graphics, text, multimedia, and the like. The mobile device's browser application may employ virtually any programming language, including a wireless application protocol messages (WAP), and the like. In at least one embodiment, the browser application is enabled to employ Handheld Device Markup Language (HDML), Wireless Markup Language (WML), WMLScript, JavaScript, Standard Generalized Markup Language (SGML), HyperText Markup Language (HTML), eXtensible Markup Language (XML), HTML5, and the like.

Memory **304** may include Random Access Memory (RAM), Read-Only Memory (ROM), and/or other types of memory. Memory **304** illustrates an example of computer-readable storage media (devices) for storage of information such as computer-readable instructions, data structures, program modules or other data. Memory **304** stores a basic input/output system (BIOS) **308** for controlling low-level operation of mobile device **300**. The memory also stores an operating system **306** for controlling the operation of mobile device **300**. It will be appreciated that this component may include a general-purpose operating system such as a version of UNIX, or LINUX™, or a specialized mobile computer communication operating system such as Windows Mobile™, or the Symbian® operating system. The operating system may include, or interface with a Java virtual machine module that enables control of hardware components and/or operating system operations via Java application programs.

Memory **304** further includes one or more data storage **310**, which can be utilized by mobile device **300** to store, among other things, applications **320** and/or other data. For example, data storage **310** may also be employed to store information that describes various capabilities of mobile device **300**. The information may then be provided to another device based on any of a variety of events, including being sent as part of a header during a communication, sent upon request, or the like. Data storage **310** may also be employed to store social networking information including address books, buddy lists, aliases, user profile information, or the like. Data storage **310** may further include program code, data, algorithms, and the like, for use by a processor, such as processor **302** to execute and perform actions. In one embodiment, at least some of data storage **310** might also be stored on another component of mobile device **300**, including, but not limited to, non-transitory processor-readable removable storage device **336**, processor-readable stationary storage device **334**, or even external to the mobile device. Data storage **310** may include, for example, file data **314**, snapshot data **316**, or the like.

Applications **320** may include computer executable instructions which, when executed by mobile device **300**, transmit, receive, and/or otherwise process instructions and data. Applications **320** may include, for example, replication and restoration application **322**, and file system application **324**. Other examples of application programs include calendars, search programs, email client applications, IM applications, SMS applications, Voice Over Internet Protocol (VOIP) applications, contact managers, task managers, transcoders, database programs, word processing programs, security applications, spreadsheet programs, games, search programs, and so forth.

Illustrative Network Device

FIG. **4** shows one embodiment of network device **400** that may be included in a system implementing the invention. Network device **400** may include many more or less components than those shown in FIG. **4**. However, the components shown are sufficient to disclose an illustrative embodiment for practicing the present invention. Network device **400** may represent, for example, one embodiment of at least one of network device **112**, **114**, or **120** of FIG. **1**.

As shown in the figure, network device **400** includes a processor **402** in communication with a memory **404** via a bus **428**. Network device **400** also includes a power supply **430**, network interface **432**, audio interface **456**, display **450**, keyboard **452**, input/output interface **438**, processor-readable stationary storage device **434**, and processor-readable removable storage device **436**. Power supply **430** provides power to network device **400**.

Network interface **432** includes circuitry for coupling network device **400** to one or more networks, and is constructed for use with one or more communication protocols and technologies including, but not limited to, protocols and technologies that implement any portion of the Open Systems Interconnection model (OSI model), global system for mobile communication (GSM), code division multiple access (CDMA), time division multiple access (TDMA), user datagram protocol (UDP), transmission control protocol/Internet protocol (TCP/IP), Short Message Service (SMS), Multimedia Messaging Service (MMS), general packet radio service (GPRS), WAP, ultra wide band (UWB), IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMax), Session Initiation Protocol/Real-time Transport Protocol (SIP/RTP), or any of a variety of other wired and wireless communication protocols. Network interface **432** is sometimes known as a transceiver, transceiving device, or network interface card (NIC). Network device **400** may optionally communicate with a base station (not shown), or directly with another computing device.

Audio interface **456** is arranged to produce and receive audio signals such as the sound of a human voice. For example, audio interface **456** may be coupled to a speaker and microphone (not shown) to enable telecommunication with others and/or generate an audio acknowledgement for some action. A microphone in audio interface **456** can also be used for input to or control of network device **400**, for example, using voice recognition.

Display **450** may be a liquid crystal display (LCD), gas plasma, electronic ink, light emitting diode (LED), Organic LED (OLED) or any other type of light reflective or light transmissive display that can be used with a computing device. Display **450** may be a handheld projector or pico projector capable of projecting an image on a wall or other object.

Network device **400** also may also comprise input/output interface **438** for communicating with external devices not shown in FIG. **4**. Input/output interface **438** can utilize one or more wired or wireless communication technologies, such as USB™, Firewire™, WiFi, WiMax, Thunderbolt™, Infrared, Bluetooth™, Zigbee™, serial port, parallel port, and the like.

Human interface components can be physically separate from network device **400**, allowing for remote input and/or output to network device **400**. For example, information routed as described here through human interface components such as display **450** or keyboard **452** can instead be routed through the network interface **432** to appropriate human interface components located elsewhere on the network. Human interface components include any component that allows the computer to take input from, or send output to, a human user of a computer.

Memory **404** may include Random Access Memory (RAM), Read-Only Memory (ROM), and/or other types of memory. Memory **404** illustrates an example of computer-readable storage media (devices) for storage of information such as computer-readable instructions, data structures, program modules or other data. Memory **404** stores a basic input/output system (BIOS) **408** for controlling low-level operation of network device **400**. The memory also stores an operating system **406** for controlling the operation of network device **400**. It will be appreciated that this component may include a general-purpose operating system such as a version of UNIX, or LINUX™, or a specialized operating system such as Microsoft Corporation's Windows® operating system, or the Apple Corporation's IOs® operating system. The operating system may include, or interface with a Java virtual machine module that enables control of hardware components and/or operating system operations via Java application programs.

Memory **404** further includes one or more data storage **410**, which can be utilized by network device **400** to store, among other things, applications **420** and/or other data. For example, data storage **410** may also be employed to store information that describes various capabilities of network device **400**. The information may then be provided to another device based on any of a variety of events, including being sent as part of a header during a communication, sent upon request, or the like. Data storage **410** may also be employed to store social networking information including address books, buddy lists, aliases, user profile information, or the like. Data stores **410** may further include program code, data, algorithms, and the like, for use by a processor, such as processor **402** to execute and perform actions. In one embodiment, at least some of data store **410** might also be stored on another component of network device **400**, including, but not limited to, non-transitory media inside processor-readable removable storage device **436**, processor-readable stationary storage device **434**, or any other computer-readable storage device within network device **400**, or even external to network device **400**. Data storage **410** may include, for example, file store **412**, snapshot data **416**, and mapping tables **418**.

Applications **420** may include computer executable instructions which, when executed by network device **400**, transmit, receive, and/or otherwise process messages (e.g., SMS, Multimedia Messaging Service (MMS), Instant Message (IM), email, and/or other messages), audio, video, and enable telecommunication with another user of another mobile device. Other examples of application programs include calendars, search programs, email client applications, IM applications, SMS applications, Voice Over Internet Protocol (VOIP) applications, contact managers, task managers, transcoders, database programs, word processing programs, security applications, spreadsheet programs, games, search programs, and so forth. Applications **420** may include, for example, replication and restoration application **422**, and file system application **424**.

Illustrative Logical Operations

In at least one of the various embodiments, a primary file system cluster may be arranged with another secondary file system cluster providing backup and/or redundancy for the primary file system cluster. Thus, if the primary file system cluster should become unavailable the secondary file system cluster may take over its responsibilities.

In at least one of the various embodiments, a secondary file system cluster may be arranged to mirror the contents of a primary file system cluster. Accordingly, in at least one of the various embodiments, periodically the contents and/or state of the primary file system cluster may be transferred and committed to the secondary file system cluster.

In at least one of the various embodiments, if a primary file system cluster fails or becomes unavailable while the mirroring process is active, there is a probability that the file system content/state on the secondary file system cluster to be inconsistent. Accordingly, effective mirroring/backup procedures may include protocols that may be sufficient to retain file system consistency in the face of failure during the mirroring process.

In at least one of the various embodiments, replication and restoration application (RRA) **422** may be enabled to commit changes from the primary file system cluster to the secondary file system cluster using a transaction based protocol. Such a protocol may enable the file system application to receive insurances from RRA **422** that up to the point-in-time of the last backup transaction, data on the secondary file system cluster may be consistent.

FIG. **5** illustrates an overview of file system cluster backup/mirroring in accordance with at least one of the various embodiments. In at least one of the various embodiments, primary file system cluster **502** (Cluster A) and secondary file system cluster **504** (Cluster B) may be enabled to communicate over network **506**.

In at least one of the various embodiments, file system cluster **504** may be arranged to mirror and/or backup file system cluster **502**. Thus, in this example, file system cluster **502** may be the primary file system cluster and file system cluster **504** may be the secondary file system cluster.

In at least one of the various embodiments, RRA **422** may be arranged to mirror primary file system cluster **502** by periodically transferring the changes that may have occurred between two versions of the primary file system cluster. In at least one of the various embodiments, the versions may be demarked by snapshots generated on the primary file system cluster.

In at least one of the various embodiments, snapshot **508** represents a point-in-time state of file system cluster **502**. In at least one of the various embodiments, snapshot **508** may be incrementally synchronized to file system cluster **504** as snapshot **510**. Likewise, snapshot **512** may be incrementally synchronized resulting in snapshot **514** on file system cluster **504**.

In at least one of the various embodiments, incremental synchronization transfers changes from the primary file system cluster to the secondary file system cluster. In at least one of the various embodiments, the synchronization is incremental because it may take several network transactions to complete the process of generating a synchronized snapshot.

In at least one of the various embodiments, incremental synchronization process **516**A illustrates committing the changes from file system cluster **502** such that snapshot **510** mirrors snapshot **508**. Likewise, in at least one of the various embodiments, incremental synchronization process **516**B illustrates committing the changes from file system cluster **502** such that snapshot **512** mirrors snapshot **514**. However, the synchronization of snapshot **518** has not completed. Thus, in at least one of the various embodiments, if file system cluster **502** (Cluster A) becomes unavailable RRA **422** may provide consistent data on secondary file system cluster **504** corresponding to snapshot **512**. In at least one of the various embodiments, this may be because the incremental synchronization corresponding to snapshot **518** may not have completed before file system cluster **502** became unavailable. Thus, the most recent synchronized snapshot available on file system cluster **504** may be snapshot **514**.

FIGS. **6**A-**6**D illustrate an overview of the failover-failback procedure in accordance with at least one of the various embodiments. These figures illustrate for at least one of the various embodiments, the logical operations involved in a failover and a subsequent failback.

For at least one of the various embodiments, FIG. **6**A shows file system cluster **602** and file system cluster **604** arranged such that file system cluster **602** may be a primary file system cluster and file system cluster **604** may be a secondary file system cluster (secondary to file system cluster **602**). The axis **606** and **608** represent increasing time as changes may be made to the file system clusters.

In at least one of the various embodiments, primary file system cluster **602** and secondary file system cluster **604** may be synchronized to snapshot S**1**. Snapshot **610** on primary file system cluster **602** and snapshot **614** on secondary file system cluster **604** may be considered to be synchronized snapshots.

In this example, in at least one of the various embodiments, subsequently snapshot **612** (S**2**) may be generated on file system cluster **602**. In at least one of the various embodiments, RRA **422** may be employed to determine snapshot change set **616** that represents the changes to file system cluster **602** that may have occurred since snapshot **601** (S**1**) and until snapshot **612** (S**2**) was generated. Accordingly, in at least one of the various embodiments, incremental synchronization process **618** may be initiated by RRA **422** to commit snapshot change set **616** to file system cluster **604**. In at least one of the various embodiments, partial snapshot change set **620** may be generated by RRA **422** as the incremental synchronization process proceeds. In at least one of the various embodiments, if incremental synchronization process **618** runs to completion, file system cluster **604** may generate a snapshot equivalent to snapshot **612**.

In at least one of the various embodiments, snapshot change sets may include a plurality of changes that may be incrementally committed on a target file system cluster, such as file system cluster **604**. In at least one of the various embodiments, as the changes may be received from the source file system cluster the changes may be executed on the target file system cluster.

Continuing with this example, FIG. **6**B shows for at least one of the various embodiments the incremental synchronization process **616** making an unplanned exit. In at least one of the various embodiments, this may be because file system cluster **602** has unexpectedly become unavailable (e.g., network failure, power loss, or the like). In at least one of the various embodiments, if file system cluster **602** becomes unavailable before the completion of incremental synchronization process **616**, file system cluster **604** may have an inconsistent mirror/backup the primary file system cluster's (file system cluster **602**) data. The secondary file system cluster, file system cluster **604** may have received and committed just a portion of snapshot change set **616**, this partial snapshot change set **620** represents an indeterminate transfer of data and state from snapshot change set **616**.

In at least one of the various embodiments, if the primary file system cluster becomes unavailable, the secondary file system cluster may be brought online as the active file cluster. In at least one of the various embodiments, this process may be the failover process, where the distributed file system fails over from the primary file system cluster to the backup secondary file system cluster. Thus, in this example, file system cluster **604** may be activated and brought online to provide file system services while file system cluster **602** may be unavailable.

However, in at least one of the various embodiments, file system cluster **604** may be in an inconstant state, or it may include an inconsistent/indeterminate mirror of the data of file system cluster **602**. Thus, before being activated and brought online file system cluster may be restored to a consistent state. In this example, in at least one of the various embodiments, restoring file system cluster **604** to snapshot **614** may return it to the most recent consistent mirror of file system cluster **602**. Accordingly, changes corresponding to partial snapshot change set **620** may be undone/reversed. In at least one of the various embodiments, snapshot **614** may be a synchronized snapshot because it may be known to be consistent with snapshot **610** on file system cluster **602**.

In FIG. **6**C, in at least one of the various embodiments, file system cluster **604** may be active and online, providing file system services for users and processes. In at least one of the various embodiments, eventually file system cluster **602** may become available and ready to be restored to the active/primary file system cluster. For example, if the problem that caused file system cluster **602** to become unexpectedly unavailable may be resolved.

In at least one of the various embodiments, a failback procedure must be completed before file system cluster **602** may be brought back online as the primary file system cluster. In at least one of the various embodiments, the failback process may be processed differently than the failover process because it is a controlled process rather than unexpected.

In at least one of the various embodiments, file system cluster **602** may be restored to a point-in-time state that RRA **422** knows is consistent on the secondary file system cluster, file system cluster **604**. In this example, S**1** is a synchronized snapshot that is consistent on both file system clusters. Accordingly, RRA **422** may restore file system cluster **602** to a state corresponding to snapshot **610**. In at least one of the various embodiments, RRA may discard snapshot **612** and snapshot delta **616** (shown in FIG. **6**A).

In at least one of the various embodiments, in preparation for restoring file system cluster **602** and bringing it online as the primary file system cluster, the data changes made on file system cluster **604** need to be determined and committed to file system cluster **604**.

In at least one of the various embodiments, because the failback process is a controlled process, RRA **422** may obtain a lock on file system cluster **604** that may prevent changes from occurring during the failback process.

In at least one of the various embodiments, RRA **422** may generate snapshot **622** (S**3**) on file system cluster **604**. From snapshot **614** (S**1**) and snapshot **622** (S**3**), RRA may determine the snapshot delta **624**. In at least one of the various embodiments, snapshot change set **624** includes the data changes, including adds, updates, and deletes, that have occurred in the file system during the time file system cluster **604** was online (acting as the primary file system cluster).

FIG. **6**D shows for at least one of the various embodiments, incremental synchronization process **626** committing the changes in snapshot change set **624** on file system cluster **602** (e.g., partial snapshot change set **628**). In at least one of the various embodiments, if the incremental synchronization process **626** completes, each change corresponding to snapshot change set **624** is transferred to file system cluster **602** and RRA **422** may generate snapshot **603**. Thus, in this example, file system cluster **602** may be in condition to be brought back online and activated as the primary file system cluster. Likewise, file system cluster **604** may be taken offline and returned to being the secondary file system cluster (e.g., receiving backup transactions from mirroring the primary file system cluster).

Snapshot Tracking File and Snapshot Change Set

FIGS. **7**A-**7**B illustrate an logical representation of a snapshot tracking file and a snapshot change set in accordance with at least one of the various embodiments.

In at least one of the various embodiments, a snapshot tracking file tracks which file system objects have changed relative to the corresponding snapshot. In at least one of the various embodiments, being listed in a snapshot tracking file indicates that one or more changes have occurred relative to the listed file system object. In at least one of the various embodiments, the particular changes may be absent from the snapshot tracking file.

FIG. **7**A shows for at least one of the various embodiments snapshot tracking file **702** that may include tracking information for five file system objects (e.g., F**1**, F**7**, F**11**, F**12**, and F**30**). In at least one of the various embodiments, snapshot tracking file **702** may be implemented using well-known data structures such as an array, bitmask, linked list, or the like. In at least one of the various embodiments, the snapshot tracking file may grow as the number of modified file system objects increases.

In at least one of the various embodiments, if RRA **422** may employ a snapshot tracking file to generate a snapshot change set. In at least one of the various embodiments, a snapshot change set may be a data structure that includes the set of changes made to file system objects that have been changed between one or more versions and/or snapshots of a file system cluster.

In at least one of the various embodiments, RRA **422** may enumerate the snapshot tracking file to identify the particular file system object that may be included in a snapshot change set. In at least one of the various embodiments, for each file system object in the snapshot tracking list, RRA **422** may identify the changes that were made to each file system object by reviewing a file system log or by comparing file system data structures, such as, b-trees, in the snapshots and the file system. In at least one of the various embodiments, each determined change and/or modification may be associated with its corresponding file system object in the snapshot change set.

FIG. **7**B shows an example of snapshot change set **704** in accordance with at least one of the various embodiments. In this example, snapshot change set **704** includes change element **706** that includes the changes made to file system object "F**1**". In this example, between the versions compared for snapshot change set **704**, three changes (e.g., writes, updates, or moves) have occurred to file system object F**1**.

Further, in this example, change element **708** represents modifications made to file system object "F**7**." In this example, F**7** was deleted from the file system cluster subsequent to file system version/snapshot that corresponds to the snapshot change set. Likewise, change element **710** represents the modifications that occurred to F**30** since the snapshot/version was generated. In this example, F**30** was created and subsequent to its creation it was modified.

One of ordinary skill in the art will appreciate that the logical structures of the snapshot tracking file and snapshot change set may be implemented using a variety of well-known data structures, such as, arrays, linked lists, indices, or the like, and the examples used herein are non-limiting and sufficient to disclose at least what is claimed.

FIG. **8** shows logical representations of cluster logical inode (LIN) maps in accordance with at least one of the various embodiments. In at least one of the various embodiments, each file system cluster maintains independent LIN values for stored file system objects.

In at least one of the various embodiments, if file system clusters may be arranged into a primary-secondary cluster relationship they may employ LIN maps to map between LIN's that are local LIN and remote LIN in another cluster. Accordingly, in at least one of the various embodiments, primary file system clusters may maintain a LIN Map that may be used to map LINs from the secondary file system clusters to local LINs. Likewise, in at least one of the various embodiments, secondary file system clusters may maintain LIN maps that map between local LIN's and LIN's on the primary file system cluster.

In at least one of the various embodiments, LIN Map **802** may be a logical representation of a map data structure that may be stored on a primary file system cluster. Also, in at least one of the various embodiments, LIN Map **804** may be a logical representation of a LIN map data structure that may be stored on a secondary file system cluster.

In at least one of the various embodiments, the LIN maps may be used to map between LIN included associated with changes in a snapshot change set generated on one file system cluster to LIN values on another file system cluster. In at least one of the various embodiments, each LIN map may be an inverse of each other. In at least one of the various embodiments, by example, row **806** illustrates a mapping between LIN F**6** and F**14**. LIN F**6** is the local LIN in the cluster for the item and F**14** corresponds to the LIN value of the item on the remote cluster. Likewise, row **808** maps between a local LIN value of F**14** and a remote LIN value of F**6**.

In at least one of the various embodiments, file system objects that were deleted may be regenerated during a restore process. Accordingly, new LIN values may generated for the regenerate file system objects. In at least one of the various embodiments, from the perspective of the file system, since snapshot based restoration of deleted file system objects may be treated similar to creating new file system objects, the file system may assign new LINs for all restored file system objects. In at least one of the various embodiments, since the LIN map may have mappings in terms of the old LINs the snapshot restore processes on both primary file system clusters and secondary file system clusters may each maintain an additional LIN map that maps old LINs to new LINs for restored files.

In at least one of the various embodiments, a LIN map synchronization phase may be employed to exchange old-to-new LIN mappings between primary file system clusters and secondary file system clusters. In at least one of the various embodiments, this may provide the file systems clusters an opportunity send a query to another file system cluster to determine LINs for which the remote equivalent may be unknown. In at least one of the various embodiments, the set of restored LINs may be different for each file system cluster, so this exchange may happen bi-directionally.

Generalized Operations

FIG. **9** shows a flow chart for process **900** of restoring/replicating changes to a file system made in between snapshots in accordance with at least one of the various embodiments. After a start block, at block **902**, in at least one of the various embodiments, determine a snapshot and a version in the file system cluster. In at least one of the various embodiments, the file system cluster may be the source of a restoration and/or replication operation. In at least one of the various embodiments, a first and second snapshot in the source cluster may be determined wherein the second snapshot demarks a version of the file system.

At block **904**, in at least one of the various embodiments, identify modified files using the snapshot tracking file corresponding to the snapshot.

At block **906**, in at least one of the various embodiments, generate a snapshot change set based on the actions taken for each file identified in the snapshot tracking file.

At block **908**, in at least one of the various embodiments, incrementally commit the snapshot change set to the target file system cluster. In at least one of the various embodiments, each change in the snapshot change set may be committed to the target file system cluster.

In at least one of the various embodiments, in some cases, the source file system cluster and the target file system cluster may be the same file system cluster. For example, in at least one of the various embodiments, the source file system cluster and the target file system cluster may be the same file cluster if restoring to a snapshot/version.

In at least one of the various embodiments, RRA **422** may be configured to execute/commit the file system object changes included in a snapshot change in a particular order. In at least one of the various embodiments, order may be changed based on the characteristics of particular file system. In at least one of the various embodiments, RRA **422** may first execute/commit the delete changes (e.g., changes may correspond to the deletion of file system object), followed by changes associated with hard links (e.g., moves and directory creates), and finally inode meta-data changes (e.g., block count updates, size, last access time, or the like) and data updates.

At decision block **910**, in at least one of the various embodiments, if the snapshot change set has been successfully committed to the target file system cluster, control may move to block **912**. Otherwise, in at least one of the various embodiments, control may loop back to block **908** to continue the incremental commit process.

In at least one of the various embodiments, each snapshot change set may include one or more changes to any given file system object. Accordingly, in at least one of the various embodiments, for some file system objects, committing a snapshot change set may result in more than one change being applied.

Also, in at least one of the various embodiments, if a file system cluster is being restored to a version or a snapshot committing the snapshot change set result in the reversal of one or more changes that were made to the file.

In at least one of the various embodiments, if a delete of a file system object is being reversed by RRA **422**, the data to restore the file system object may be retrieved from the snapshot and stored/regenerated into the file system cluster.

At block **912**, in at least one of the various embodiments, the target cluster may generate a snapshot that corresponds to the committed changes from the snapshot change set. Next, in at least one of the various embodiments, control may be retuned to a calling process.

In at least one of the various embodiments, the snapshot tracking file may be restricted to include LIN's of file system objects that have been modified. Thus, in at least one of the various embodiments, the operational/performance load of the replication/restoration process grows based on the number of changes made between the file system cluster versions, independent from the number of files in the file system.

FIG. **10** shows a flow chart for process **1000** of failover and failback between a primary file system cluster and a secondary file system cluster. After a start block, at block **1002**, in at least one of the various embodiments, incrementally commit the snapshot change set from the primary file system cluster to the secondary file system cluster.

At decision block **1004**, in at least one of the various embodiments, if the primary file system cluster becomes unavailable, control may move to block **1008**. Otherwise, in at least one of the various embodiments, control may move to decision block **1006**.

In at least one of the various embodiments, a primary file system cluster may become unavailable for various reasons such as, power failure, network failure, or the like.

At decision block **1006**, in at least one of the various embodiments, if there may be changes in the snapshot change set to commit to the target file system cluster, control may loop back to block **1002**. Otherwise, in at least one of the various embodiments, control may be returned to calling process.

At block **1008**, in at least one of the various embodiments, failover from the primary file system cluster to the secondary file system cluster and activate the secondary file system cluster.

At decision block **1010**, in at least one of the various embodiments, if the primary file system cluster becomes available, control may move to block **1012**. Otherwise, in at least one of the various embodiments, control may loop back to block **1008**.

At block **1012**, in at least one of the various embodiments, failback from the secondary file system cluster to the primary file system cluster and activate the primary file system cluster if the failback completes. Next, in at least one of the various embodiments, control may be returned to a calling process.

FIG. **11** shows a flow chart for process **1100** for failover in accordance with at least one of the various embodiments. After a start block, at block **1102**, in at least one of the various embodiments, a snapshot delta data may be received from a primary file system cluster.

At decision block **1104**, in at least one of the various embodiments, if the primary file system cluster may become unavailable during the incremental committing of a snapshot change set control may move to block **1106**. Otherwise, in at least one of the various embodiments, control may loop back to block **1102**.

In at least one of the various embodiments, the secondary file system cluster may have received a partial snapshot change set because some changes in the snapshot change set from the primary file system cluster remain uncommitted on the secondary file system cluster.

At block **1106**, in at least one of the various embodiments, restore the state of the secondary file system cluster to the last complete synchronized snapshot.

In at least one of the various embodiments, the snapshot tracking file corresponding to the last synchronized snapshot on the secondary file system cluster may be used to generate a snapshot change set. This snapshot change set may be employed to restore the secondary file system cluster to the version/state that corresponds to the last synchronized snapshot.

In at least one of the various embodiments, because this may be a restore operation the changes in the snapshot change set may be applied to reverse the modification that were made to the file system objects.

At block **1108**, in at least one of the various embodiments, activate the secondary file system cluster to begin providing file system services instead of the primary file system cluster. In at least one of the various embodiments, if the secondary file system cluster may be restored to a synchronized snapshot, it may begin providing file system services to users.

FIG. **12** shows a flow chart for process **1200** for failback process in accordance with at least one of the various embodiments. After a start block, at decision block **1202**, if the primary file system cluster becomes available, control may move to block **1204**. Otherwise, in at least one of the various embodiments, control may return to a calling process.

In at least one of the various embodiments, the primary file system cluster may become available if the reason(s) for its unavailability has been resolved (e.g., restoration of power). However, the primary file system may not be ready to activate because the secondary file system cluster may have been processing user file system requests/operations while the primary file cluster was unavailable.

In at least one of the various embodiments, the primary file system cluster needs to be synchronized with the secondary file system cluster before it may be activated.

At block **1204**, in at least one of the various embodiments, restore the primary file system cluster to the last stable synchronized snapshot.

In at least one of the various embodiments, to establish a starting point for the synchronization process that primary file system cluster may restored to the last synchronized snapshot. This may be the last snapshot synchronized before the primary file system cluster became unavailable.

In at least one of the various embodiments, there may likely be data on the primary file system cluster that was not synchronized with the secondary file system cluster, this data may be discarded. In at least one of the various embodiments, the data may be discarded by performing a snapshot restore that reverses/undo's modification made to file system object subsequent to the last synchronized snapshot.

At block **1206**, in at least one of the various embodiments, obtain a lock on the secondary file system cluster to prevent changes to the file system data during failback.

In at least one of the various embodiments, the failback process may be a controlled operation because it happens under the control of the users/administrators. Thus, in at least one of the various embodiments, the file system may be locked during to the failback process to establish data consistency between the primary file system cluster and the secondary file system cluster.

At block **1208**, in at least one of the various embodiments, generate a current snapshot on the secondary file system cluster.

In at least one of the various embodiments, the failback process may synchronize the primary file system cluster with this current snapshot of the secondary file system. In at least one of the various embodiments, it may be used to establish a new baseline for mirroring between the two clusters.

At block **1210**, in at least one of the various embodiments, generate a snapshot change set and incrementally commit the corresponding changes on the primary file system cluster.

In at least one of the various embodiments, this snapshot change set may include the changes to file system objects that may have occurred since the secondary file system cluster was activated (e.g., since the failover process). In at least one of the various embodiments, the secondary file system cluster may include intervening snapshots that were generated on the secondary file system cluster during the period when the primary file system was unavailable. If so, in at least one of the various embodiments, changes associated with these intervening snapshots may be restored on the primary file system cluster as well.

At block **1212**, in at least one of the various embodiments, activate the primary file cluster. Also, in at least one of the various embodiments, the secondary file system cluster may be placed back into a mirroring/backup role. Next, control may be returned a calling process.

It will be understood that figures, and combinations of actions in the flowchart-like illustrations, can be implemented by computer program instructions. These program instructions may be provided to a processor to produce a machine, such that the instructions executing on the processor create a means for implementing the actions specified in the flowchart blocks. The computer program instructions may be executed by a processor to cause a series of operational actions to be performed by the processor to produce a computer implemented process for implementing the actions specified in the flowchart block or blocks. These program instructions may be stored on some type of machine readable storage media, such as processor readable non-transitive storage media, or the like.

The invention claimed is:

1. A method for managing at least one change in a file system for a plurality of network devices, wherein at least one network device is operative to perform actions, comprising:

determining by a source file system cluster at least one snapshot and at least one version of a state of the source file system cluster, wherein each snapshot corresponds to a snapshot tracking file;

determining at least one changed file system object that is in a snapshot tracking file that corresponds to a determined snapshot;

generating at least one snapshot change set based on each change to each changed file system object in the snapshot tracking file wherein the at least one snapshot change set includes at least a deletion, a move, and an update;

incrementally committing the snapshot change set to at least one target file system cluster in the following order:

first, executing each change on the target file system cluster that corresponds to deleting at least one file system object;

second, executing each change on the target file system cluster that corresponds to moving at least one file system object, or generating at least one new file system object; and

third, executing each change on the target file system cluster that corresponds to updating at least one file system object; and

if the snapshot change set is fully committed on the target file system cluster, generating at least one new snapshot for the target file system cluster that represents a state of the target file system cluster and also corresponds to the committed snapshot change set.

2. The method of claim **1** further comprising, if the source file system cluster is a primary file system cluster and the target file system cluster is a corresponding secondary file system cluster and the primary file system cluster is unavailable prior to fully committing the snapshot change set, perform further actions, comprising:

restoring the secondary file system cluster to a last synchronized snapshot; and

enabling the secondary file system cluster to provide file system services instead of the primary file system cluster.

3. The method of claim **1**, further comprising, if the source file system cluster is a primary file system cluster and the target file system cluster is a corresponding secondary file system cluster and the primary file system cluster is available subsequent to enabling the secondary file system cluster to provide file system services instead of the primary file system cluster, perform further actions, comprising:

restoring the primary file system cluster to a last synchronized snapshot;

obtaining a lock on the secondary file system cluster, wherein the lock at least prevents a change to each file system object on the secondary file system cluster;

generating a failback snapshot change set based on at least each change made to at least each file system object in the secondary file system cluster since the last synchronized snapshot was generated;

fully committing each change in the failback snapshot change set to at least the primary file system cluster; and

enabling the primary file system cluster to provide file system services instead of the secondary file system cluster.

4. The method of claim **1**, further comprising:

generating a logical inode (LIN) map on each file system cluster, wherein the LIN map on the source file system cluster and the LIN map on the target file system cluster are at least an inverse of each other; and

if the target file system cluster is separate from the source file system cluster, exchange LIN map data between the source file system cluster and the target file system cluster.

5. The method of claim **1**, wherein committing the snapshot change set further comprises performing each change in reverse if the target file system cluster is being restored to the version that corresponds to the snapshot.

6. The method of claim **1**, further comprising at least one of:

enabling the source file system cluster and the target file system cluster to operate on the same network devices; and

enabling the source file system cluster and the target file system cluster to operate in the same file system cluster.

7. A plurality of file system clusters, including a source file system cluster and a target file system cluster, for managing at least one change in a file system over a network, wherein file system clusters among the plurality of file system clusters include at least one storage device and at least one hardware processor configured to:

determine by the source file system cluster at least one snapshot and at least one version of a state of the source file system cluster, wherein each snapshot corresponds to a snapshot tracking file;

determine by the source file system cluster at least one changed file system object that is in a snapshot tracking file that corresponds to a determined snapshot;

generate by the source file system cluster at least one snapshot change set based on each change to each changed file system object in the snapshot tracking file wherein the at least one snapshot change set includes at least a deletion, a move, and an update;

incrementally commit the snapshot change set to the target file system cluster in the following order:

first, executing each change on the target file system cluster that corresponds to deleting at least one file system object;

second, executing each change on the target file system cluster that corresponds to moving at least one file system object, or generating at least one new file system object; and

third, executing each change on the target file system cluster that corresponds to updating at least one file system object; and

in response to fully committing the snapshot change set to the target file system cluster, generate at least one new snapshot for the target file system cluster that represents a state of the target file system cluster and also corresponds to the committed snapshot change set.

8. The plurality of file system clusters of claim **7**, further comprising, if the source file system cluster is a primary file system cluster and the target file system cluster is a corresponding secondary file system cluster and the primary file system cluster is unavailable prior to fully committing the snapshot change set, perform further actions, comprising:

restore the secondary file system cluster to a last synchronized snapshot; and

enable the secondary file system cluster to provide file system services instead of the primary file system cluster.

9. The plurality of file system clusters of claim **7**, further comprising, if the source file system cluster is a primary file system cluster and the target file system cluster is a corresponding secondary file system cluster and the primary file system cluster is available subsequent to enabling the secondary file system cluster to provide file system services instead of the primary file system cluster, perform further actions, comprising:

restore the primary file system cluster to a last synchronized snapshot;

obtain a lock on the secondary file system cluster, wherein the lock at least prevents a change to each file system object on the secondary file system cluster;

generate a failback snapshot change set based on at least each change made to at least each file system object in the secondary file system cluster since the last synchronized snapshot was generated;

fully commit each change in the failback snapshot change set to at least the primary file system cluster; and

enable the primary file system cluster to provide file system services instead of the secondary file system cluster.

10. The plurality of file system clusters of claim **7**, further comprising:

generate a logical inode (LIN) map on each file system cluster, wherein the LIN map on the source file system cluster and the LIN map on the target file system cluster are at least an inverse of each other; and

if the target file system cluster is separate from the source file system cluster, exchange LIN map data between the source file system cluster and the target file system cluster.

11. The plurality of file system clusters of claim **7**, wherein committing the snapshot change set further comprises performing each change in reverse if the target file system cluster is being restored to the version that corresponds to the snapshot.

12. The plurality of file system clusters of claim **7**, further comprising at least one of:

enable the source file system cluster and the target file system cluster to operate on the same network devices; and

enable the source file system cluster and the target file system cluster to operate in the same file system cluster.

13. A processor readable non-transitory storage media with instructions for managing at least one change in a file system for a plurality of file system clusters over a network, wherein execution of the instructions by a processor enables actions, comprising:

Determining by a source file system cluster at least one snapshot and at least one version of a state of the source file system cluster, wherein each snapshot corresponds to a snapshot tracking file;

determining at least one changed file system object that is in a snapshot tracking file that corresponds to a determined snapshot;

generating at least one snapshot change set based on each change to each changed file system object in the snapshot tracking file wherein the at least one snapshot change set includes at least a deletion, a move, and an update;

incrementally committing the snapshot change set to a target file system cluster in the following order:

first, executing each change on the target file system cluster that corresponds to deleting at least one file system object;

second, executing each change on the target file system cluster that corresponds to moving at least one file system object, or generating at least one new file system object; and

third, executing each change on the target file system cluster that corresponds to updating at least one file system object; and

if the snapshot change set is fully committed on the target file system cluster, generating at least one new snapshot for the target file system cluster that represents a state of the target file system cluster and also corresponds to the committed snapshot change set.

14. The media of claim **13**, further comprising, if the source file system cluster is a primary file system cluster and the target file system cluster is a corresponding secondary file system cluster and the primary file system cluster is unavailable prior to fully committing the snapshot change set, perform further actions, comprising:

restoring the secondary file system cluster to a last synchronized snapshot; and

enabling the secondary file system cluster to provide file system services instead of the primary file system cluster.

15. The media of claim **13**, further comprising, if the source file system cluster is a primary file system cluster and the target file system cluster is a corresponding secondary file system and the primary file system cluster is available subsequent to enabling the secondary file system cluster to provide file system services instead of the primary file system cluster, perform further actions, comprising:

restoring the primary file system cluster to a last synchronized snapshot;

obtaining a lock on the secondary file system cluster, wherein the lock at least prevents a change to each file system object on the secondary file system cluster;

generating a failback snapshot change set based on at least each change made to at least each file system object in the secondary file system cluster since the last synchronized snapshot was generated;

fully committing each change in the failback snapshot change set to at least the primary file system cluster; and

enabling the primary file system cluster to provide file system services instead of the secondary file system cluster.

16. The media of claim **13**, further comprising:

generating a logical inode (LIN) map on each file system cluster, wherein the LIN map on the source file system cluster and the LIN map on the target file system cluster are at least an inverse of each other; and

if the target file system cluster is separate from the source file system cluster, exchange LIN map data between the source file system cluster and the target file system cluster.

17. The media of claim **13**, wherein committing the snapshot change set further comprises performing each change in reverse if the target file system cluster is being restored to the version that corresponds to the snapshot.

18. The media of claim **13**, further comprising at least one of:

enabling the source file system cluster and the target file system cluster to operate on the same network devices; and

enabling the source file system cluster and the target file system cluster to operate in the same file system cluster.

* * * * *